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ARMY ORDNANCE

1917–1919

No. 103

No. 1942

HISTORY OF EXPLOSIVES

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919


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HISTORY OF EXPLOSIVES.

HISTORICAL RECORD OF EXPLOSIVES IN RELATION TO THE EQUIPMENT OF THE UNITED STATES ARMY.

By Maj. J. Herbert Hunter.

This handbook is issued with the understanding that it shall at .l times be given the care accorded confidential information; that ↄ portion of it shall be published by paraphrase or otherwise; and ıat it shall be returned to the office of the Chief of Ordnance when ıe person to whom it is issued leaves the military service of the nited States.

Credit should be given to Capt. C. A. Straw, jr., Lieut. T. B. 'eck, Lieut. Chas. S. Reed, Dr. A. W. Hixson, and especially Mrs. :. H. Hawes, for their part in the production of this work.

C. C. Williams,
Major General, Chief of Ordnance, U. S. A.

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EXPLOSIVES.

Chapter I.

ORGANIZATION OF ORDNANCE DEPARTMENT.

EXISTING ORGANIZATION AT BEGINNING OF WAR.

The Ordnance Department, at the beginning of the war, had a commissioned personnel of 87 for service in the various divisions, arsenals, and depots. The Gun Division, one of the five divisions of the Ordnance Department in existence at that time, had 3 commissioned officers and 7 civilians assigned to its office in Washington, and was charged with obtaining explosives and components for shell and guns.

Prior to the declaration of war congressional legislation required that all powder and high explosives used by the Government for military purposes be made at the arsenals, allowing only such quantities to be purchased from private manufacturers as the arsenals could not make.

The Army Powder Factory and High Explosives Factory were located at Picatinny Arsenal, which was also the principal depot for storage and issue of powder, ammunition, and high explosives. This arsenal also carried on experimental work in connection with the manufacture of these materials. The inspection of the material was carried on by inspectors from the arsenal, the Navy, until March, 1916, cooperating with the Army in this work. Most of the firings were made at Sandy Hook Proving Ground. All of this work, however, came under the jurisdiction of the Gun Division.

Preparations for war in the spring of 1917 developed large requirements for high explosives and powder, and as the arsenals could be depended on to furnish only a small portion of the amounts needed, the restrictions placed by Congress as to the manufacture of this material were removed by legislation, allowing the placing of orders with private manufacturers. It became necessary to develop an extensive organization in order to properly take care of this as well as other parts of the Ordnance program.

The Supply Division was established May 23, 1917, with Col. Charles B. Wheeler in charge. It was the duty of this division to "take charge of all ordnance and ordnance stores procured by purchase or manufacture for issue to the military service." This included propellants and high explosives. The Supply Division also arranged "for the shipment of this material to the proper points for its storage and custody, for its preservation from deterioration, and for its issue to the service." On July 1, 1917, this division had developed a personnel of 12 commissioned officers and 63 civilian employees.

Office Order No. 8, dated May 31, 1917, increased the organization to 10 divisions of Ordnance. It was under this organization the Inspection Division came into existence under Lieut. Col. B. W. Dunn, until September 6, 1917, took over the inspection of artillery ammunition, including explosives, and trench warfare material.

The Gun Division, which at the beginning of the war had a personnel of 3 commissioned officers and 7 civilian employees, with Col. Jay E. Hoffer in charge, grew rapidly, and, in accordance with Gun Division Order No. 4, dated September 7, 1917, was divided into 5 sections, under which branches were later established. Four of these sections, the Design, Purchase, Production, and Inspection, through their respective Explosives Branches, were concerned with the design, purchase, production, and inspection of powder and high explosives.

The Design Section, under control of Col. Edward P. O'Hern, was charged with all matters relating to design and specifications, and technical problems, concerning explosives and components for shell and guns, and until the Purchase and Production Sections began to function, the Explosives Branch of the Design Section, under Maj. J. H. Burns, had charge of the design, procurement, and production of high explosives and propellants. In July, 1917, the section had a personnel of approximately 12 commissioned officers and 25 civilian employees. In December there were that many officers in the Explosives Branch alone.

The Purchase Section was established in September, 1917, under Maj. C. F. Cook, and on October 1, 1917, the Explosives Branch took charge of matters relating to the purchase of explosives going into the manufacture of ordnance material. This organization increased to approximately 15, 7 being commissioned officers.

The Production Section, under Maj. H. A. Gillis, was organized about the same time as the Purchase Section, and was responsible for the production of explosives and components for shell and guns. It was late in December, 1917, that the Explosives Branch began its activities toward supervising and regulating the production of propellants and high explosives, and was placed in charge of Maj. Burns, who was also the Chief of Explosives Branch of the Design Section. The force was less than 12, including 5 commissioned officers.

On September 6, 1917, the Inspection Division, by Office Order No. 45, was made a section of the Gun Division, with Lieut. Col. B. W. Dunn in charge. The Powder and Explosives Section had been organized since June 15, when, with First Lieut. F. H. Miles, jr., as chief, and a personnel of 1 commissioned officer as assistant and several civilian clerks, the office was located at Wilmington, Del., and was charged with the inspection of high explosives and powder, and their assembly into charges or in shell. In July the office moved to Washington, where the personnel was increased by 4 clerks and 4 stenographers. Later the Inspection Section went to New York, where the force was increased to include 12 officers and 20 civilians working on powder, explosives, and loading matters.

REORGANIZATION SINCE BEGINNING OF WAR.

On January 14, 1918, certain changes in the organization of the Ordnance Department were authorized by Office Order No. 104. Branches designated as bureaus were established, performing certain functions for the benefit of the several divisions of the Ordnance Office and Ordnance Department at large. The branches now designated as divisions each performed a function in the procurement, production, inspection, and distribution of ordnance and ordnance stores. Of these bureaus and divisions, there were four under whose control came all matters relating to powder and high explosives, except storage and issue of the finished product. These were the Engineering Bureau, which under Office Order No. 222, dated May 25, 1918, became the Engineering Division, under Lieut. Col. J. H. Rice; the Procurement Division, under Col. Samuel McRoberts; the Production Division, under Col. Charles C. Jamieson; and the Inspection Division, under Lieut. Col. B. W. Dunn. Their functions were respectively, the design, procurement, production, and inspection of ordnance material. Under each of these divisions there was an Explosives Section, which took care of such explosives matters as came under the jurisdiction of the division.

The Explosives Section of the Engineering Division, which had its beginning in the Explosives Branch, Design Section, Gun Division, had as its function the design, specifications, and the solution of technical problems connected with high explosives, propellants, propellant assembly, shell filling, trench warfare explosives, primer composition, and booster explosives. Tests in connection with explosive experimental and development work were carried on under the jurisdiction of this section, in connection with which the Engineering Division had supervision of the proving grounds at Sandy Hook, N. J., Aberdeen, Md., and Rock Island Arsenal, Ill.

The Explosives Section was subdivided into the High Explosives and Research Branch, the Propellants Branch, and the Loading Branch, the functions of which are obvious. In October, 1918, the personnel of the section had increased from 8 officers and 22 civilian employees to 70, 26 being commissioned officers, with Col. C. T. Harris, jr., in charge.

The Explosives Section, Procurement Division, was originally the Explosives Branch of the Purchase Section, Gun Division. This section, under Capt. C. B. Peters, was charged with the procurement of all explosives, handling all business negotiations connected with the purchase of the explosives, not including the raw materials used in the manufacture. Beginning in January, 1918, with a personnel of 15, 7 commissioned officers and 8 civilians, under Capt. C. B. Peters, increasing to a force of 39, including 10 commissioned officers, the Explosives Section accomplished a vast amount of work.

The Production Section, Gun Division, together with the Production Section of the Carriage Division, under Office Order No. 104, became the Production Division, under Col. Guy E. Tripp (succeeded by Col. Jamieson as Chief of the Division, Aug. 22, 1918), with control over the production of all ordnance material. The division was subdivided into three sections, each having control over certain parts of this work. Explosives and their assembly into charges, and shell filling for service, came under the jurisdiction of the Explosives Section with Maj. (later Lieut. Col.) J. H. Burns in charge until April, 1918, at which time Maj. Egbert Moxham became chief. This section had absorbed a part of the old Design Section, Gun Division, and had an organized force of 20 officers and a relative number of civilian employees. As the organization grew, various branches were established, until in October, 1918, there were the Raw Materials Branch, the Procurement Branch, the High Explosives Branch, the Propellants Branch, and the Loading Branch, with a personnel of nearly 200, including about 50 officers.

The Inspection Division was a consolidation of the Inspection Section of the Gun Division with Inspection Sections of other divisions, and was subdivided into various sections. The division moved to Washington in January, 1918, where the force was greatly increased. The Explosives Section, under Lieut. Col. F. H. Miles, jr., through its various branches, i. e., the Powder and Explosives Branch, the Chemical Supervisory Branch, the Shell and Trench Warfare Loading Branch, the Fuze and Primer Loading Branch, and the Bag Loading and Pyrotechnic Branch, supervised the inspection of chemical raw materials, explosives, powder, pyrotechnic mixtures, and the loading of all artillery and trench warfare ammunition with these materials.

District offices were established in 13 cities and controlled by the Washington office through its various sections. The work of the inspectors at the plants was directly supervised by the inspection managers or their representatives stationed in the various district offices. Under the supervision of the inspection managers there were located at plants, commissioned officers known as Army inspectors of ordnance, or civilians known as chief inspectors, under whom were organized such assistants as were necessary to carry on the work. Inspection supervisors operating from the Washington office traveled from plant to plant, guiding the inspection work and assisting in the maintenance of a uniform policy.

There was established in Philadelphia, Pa., a Supervisory and Control Laboratory, whose function it was to inaugurate, control, and check standard methods of analysis, to standardize chemical equipment and apparatus, prepare standard solutions and reagents, and act as a referee in case of dispute arising over the work of the various chemists. In order to train inspectors to carry out the explosives inspection work of the Ordnance Department, there were also established three schools, a Technological School for Chemists at Carney's Point plant of the Du Pont Co., the School for Ballistic Inspectors at Kenvil plant of the Hercules Powder Co., and a Loading School for Loading Inspectors at Morgan, N. J.

The Explosives Section, in the summer of 1918, became the Explosives and Loading Branch under the Executive Section, when its various branches became known as groups. There was no change, however, in the character of its work. The organization on November 11, 1918, for the main office, district offices, and the field numbered 58 officers, 329 enlisted men, and 3,585 civilian employees.

The Operating Section of the Supply Division and also the Distribution Section through its Ammunition and Explosives Branch, supervised the storage and issue to the service of all ammunition, high explosives, and propellants.

The Operating Section under Col. C. I. De Witt had authority over all storehouses controlled by the Supply Division, maintained close relations with ordnance depots at ports of embarkation in all matters not affecting the policy of the port, and followed up, if necessary, in the field all shipments made under the direction of the Supply Division. The personnel of this section numbered 15 officers and 10 civilians.

The Ammunition and Explosives Branch, under the Distribution Section of the Supply Division, issued shipping orders for requisitions received and ordered to storage all explosive material, including loaded ammunition. It also supervised their inspection in regard to safety regulations and proper methods of storage. The Distribution Section, headed by Maj. Craig, had a personnel of 8 officers and 14 civilians.

At the time of the signing of the armistice, Col. J. C. Heckman was in charge of the entire Supply Division.

CHANGES IN ORGANIZATION.

On October 23, 1918, a change of organization was made by Office Order No. 364, when the Production Division was abolished and the Explosives and Loading Division created with Col. W. C. Spruance, jr., in charge until December 12, when, in compliance with Office Order No. 451, Col. C. T. Harris, jr., was made special assistant to the Chief of Ordnance and took charge of this division with Col. Burns as assistant. There are two sections under this division, the Explosive Section and the Loading Section. The High Explosives Branch, the Raw Materials Branch, and the Propellants Branch of the old Production Division comprise the Explosives Section, and the Loading Branch has become the Loading Section of the Explosives and Loading Division. At the time of the signing of the armistice the division had a personnel of 277, of which 42 were officers.

SPECIAL BOARDS OR COMMITTEES TO ADVISE OR CONFER WITH THE ORDNANCE DEPARTMENT.

During the years of 1917 and 1918, a number of special boards or committees were appointed to advise or confer with the Ordnance Department on various matters pertaining to explosives. These boards were of great assistance and facilitated the handling of explosive matters.

The first matter to receive the attention of a board of this kind was the nitrate problem. Heretofore, Chile had supplied this country with sodium nitrate, from which the most essential raw material for explosives and fertilizers was obtained. Because of the possibility of our being cut off from foreign supply by submarine warfare and because of the increased demand for military explosives, Congress had appropriated a sum of $20,000,000 for the production of nitrates in this country. On March 9, 1917, the Secretary of War appointed a committee, called the Nitrate Supply Committee, to consider the question of supply through the construction of Government plants. As a result of the report rendered May 11, 1917, by this committee, the Chief of Ordnance, in compliance with instructions from the Secretary of War, negotiated with the General Chemical Co., the American Cyanamid Co., and the Nitrogen Products Co., for the right to use their processes and entered into contracts for the erection of plants at Sheffield and Muscle Shoals, Ala., and at Saltsville, Va., for the fixation of atmospheric nitrogen. As a result of the recommendations of this committee, the Nitrate Division was established July 25, 1917, by Office Order No. 25½, to handle all business pertaining to nitrogen fixation.

On November 26, 1917, at the request of the United States Food Administration, an Interdepartment Coordination Committee on Ammonia was organized, consisting of representatives of the Council of National Defense, the War Department, the Navy Department, the Department of Agriculture, and the United States Food Administration. Owing to the acute ammonia situation at that time, this was considered advisable in order that the matter receive due consideration, the supply for refrigeration, ammunition, and agricultural purposes be conserved, and the distribution so controlled as to insure, as far as possible, an adequate supply for the Army and Navy, and for other essential uses. It was at the recommendation of this committee that the ammonia supply was commandeered by the War Department and distributed through the Barrett Co. and the American Cyanamid Co. to satisfactorily meet the ammonia program.

Two months later, at the suggestion of Col. P. E. Pierce of the Council of National Defense, a Committee on Explosives, consisting of representatives of the Ordnance Department, the War Industries Board, and the Navy Department, was appointed to insure the suitable exchange of current information on the explosives and smokeless powder situation in general, including the essential raw materials, with a view to coordinating and considering the relative importance of the requirements of the Allies, the Army, and the Navy, the committee's recommendations to be submitted for consideration and action to the interested branches.

In the spring of 1918, when substitute explosives and amatol mixtures for shell filling were being so deeply considered, a board of officers was appointed by the Acting Chief of Ordnance to submit recommendations as to fillers for the various sizes of shell, the information to be used in the high-explosives filling program. The board met on April 12, 1918, and submitted recommendations for the adoption of certain materials as susbstitute fillers for high-explosive shell of all calibers, trench-mortar shell, and drop bombs. To meet the estimated requirements the development of additional capacity for all these explosives was strongly urged. These recommendations were approved April 26, 1918. It was at the recommendation of this board that the use of lyconite as a bomb filler was later discontinued after such quantities as had been contracted for were exhausted.

Pursuant to the request of the Secretary of War and the Secretary of the Navy, the National Research Council formed a Committee on Explosives Investigations in August, 1918, consisting of representatives of the Ordnance Department, and the National Research

Council. The duties of this committee were to survey investigations, inventions, and improvements applicable to propellants and explosives for the Army program, and to compile a record for the information of the military and naval authorities. It cooperated with and acted in an advisory capacity in conjunction with the General Staff, Army War College.

Not only was the question of manufacture and loading of explosives considered by boards or committees but also the protection of the material and of the plants, as well as the safety of the people employed in this work. Several disasters had occurred in the spring and early summer of 1918, and it was with this in view that the Chief of Ordnance by Office Order No. 321, dated August 28, 1918, and at the recommendation of the Engineering Division, appointed a board to draw up, issue, and enforce safety regulations for loading and explosive plants. A number of meetings of the board were held, as the result of which safety operating rules were drawn up for manufacturing, loading, handling, and storing powder, explosives, and loaded shell at munitions plants operated for or by the Ordnance Department. This applied not only to safety but also to sanitation. Recommendation was made to the chiefs of the Ordnance Department district offices that as a means of enforcing these regulations, each chief appoint in his respective district a special safety engineer to handle all explosives and loading plants, this method having been successfully carried out in England.

After the signing of the armistice, there was created by Office Order No. 405, dated November 19, 1918, an Ordnance Salvage Board, consisting of seven officers, having charge of the disposition by sale or storage of all manufacturing materials, equipment, and buildings which were at that time or would later become the property of the United States, as the result of the termination of contracts made by the Ordnance Department. It was guided in its actions by such orders and regulations issued by the Director of Purchase, Storage and Traffic as were applicable to its work, and such instructions as it received from the Chief of Ordnance.

With the determination to end the war quickly and with victory for the Allied Governments, the ever-increasing explosives organization of the Ordnance Department set itself to the almost impossible task of developing and producing the explosives necessary to the accomplishment of this purpose. The very first consideration in the production of explosives was to provide for an adequate supply of the raw materials necessary. It will be interesting before going into the explosives history to give here an account of how the Ordnance Department planned to take care of the most important requirement—nitric acid.

Chapter II.

FIXATION OF ATMOSPHERIC NITROGEN.

The United States, as well as the European countries, before the outbreak of the war, had been entirely dependent upon Chile for its supply of sodium nitrate, from which nitric acid is made, nitric acid being necessary for the manufacture of practically all modern explosives. In peace times there had been no difficulty in obtaining sufficient quantities of sodium nitrate to take care of the requirements of manufacturers and even to place in storage a considerable supply. However, the possibility of war brought into serious consideration the inadvisability of the United States depending upon a foreign country for the supply of its most essential raw material for explosives, considering not only the possible interruption of commerce by the enemy but inadequate shipping facilities and the time consumed in transportation.

PROCESSES.

In Europe several processes for the fixation of atmospheric nitrogen had been successfully developed, and investigations had also been carried on in this country with some degree of success. The most successful were as follows:

(*a*) The arc process, which consists in directly combining, by means of an electric arc, the nitrogen and oxygen of the air to form nitric oxide, and then absorbing the nitric oxides in water in order to form nitric acid.

(*b*) The cyanamid process, which consists in heating calcium carbide in pure dry nitrogen whereby the latter is absorbed, forming calcium cyanamid, from which ammonia is produced by the action of superheated steam.

(*c*) The Haber process, which is the direct synthesis of ammonia from its constituents, nitrogen and hydrogen, the resultant gas being then oxidized to nitric acid.

(*d*) The nitrides process, which produces ammonia from nitrides by the action of superheated steam.

(*e*) The cyanide process, by which a mixture of sodium carbonate and coke with nitrogen is heated to form sodium cyanide, which is then decomposed with steam to yield ammonia.

INVESTIGATIONS.

The Ordnance Department had regarded with favor the investigation of these processes with a view to the erection of nitrate plants in this country, but it was not until 1916 that initial steps were taken. On June 3, 1916, by the national defense act, the sum of $20,000,000 was appropriated, which the President was empowered to use for investigations as to the best, cheapest, and most available means for the production of nitrates, by water power or other power, and for the construction of plants and their initial expenses. Several committees were organized by the National Research Council and the Secretary of War to study the situation; and the Ordnance Department with the aid of the Bureau of Mines and special agents appointed, carried on investigations covering the various processes known in this country and in Europe. The only one of these which had been in operation in America was the cyanamid. However, all the processes received thorough investigation.

It was found that while the arc process had been in commercial use in Europe, it required a great amount of electrical power, something like 10 horsepower years per ton of nitrogen fixed as nitric acid per year. This power could be obtained most cheaply by employing water as a source of energy, and it was only in such countries as Norway, with its extensive facilities for cheaply harnessing this power, that the use of the process was practical.

The nitride processes were not considered desirable, owing to the large amount of electrical power required and the undeveloped state of the process, as well as the development of more favorable processes.

The cyanamid process, although requiring relatively large amounts of power, called for only one-fourth as much as the arc, and was at that time the most highly developed method on a commercial scale, plants having been installed in European countries, and one plant in Canada by the American Cyanamid Co. at Niagara Falls, Ontario.

The sodium cyanide process, while similar to the cyanamid and requiring less power, had not reached the same degree of development as this or the Haber process, but was then under investigation by the Nitrogen Products Co. with very promising results.

The Haber process had been developed to a great extent in Europe, and Germany had depended mainly upon it for its supply of nitric acid. Less power was required than for any of the other processes and electricity was not a necessary requirement. A force of highly trained men had been essential, however, to successful operation. This process had been extensively investigated in the United States. The General Chemical Co., by certain modifications, had simplified the process to an extent where the services of men not so highly trained could be utilized, and had developed the method to a degree where several units had been operated on something more than a laboratory scale. Furthermore, the company was so confident of its value that it was about to undertake the construction of a plant of its own costing a million dollars. It was, however, willing to allow the United States to use its patent rights in the process, and to assist in the construction of a Government plant.

A committee known as the Committee on Nitrate Supply, consisting of representatives of the Army and Navy Departments, the Department of Agriculture, the Department of Commerce, and the Department of the Interior, as well as several eminent scientists and engineers, was appointed March 9, 1917, by the Secretary of War, to consider the information obtained through all other sources and to submit recommendations as to the best method of procedure.

Naturally the Haber process, as modified by the General Chemical Co., comparatively cheap, highly developed, and direct in its methods of production, appeared to be the one having the best chance of success; and the cyanide process, being cheap and so successfully developed by the Nitrogen Products Co., came next in consideration; and it was not only with these points in view but also the generous offer of the General Chemical Co. with regard to the use of its patents and its assistance in plant construction, that the Nitrate Supply Committee, on May 11, 1917, recommended that—

Negotiations be entered into with the General Chemical Co. for the right to use its processes; that contingent upon the conclusion of satisfactory negotiations, there be set aside from the $20,000,000 appropriation, a sum necessary to construct a plant having a capacity of about 60,000 pounds of ammonia every 24 hours and estimated to cost about $3,000,000; that out of the same appropriation $600,000, or as much more as needed, be set aside for operating a plant for producing, by the oxidation of ammonia, about 24,000 pounds of 100 per cent nitric acid every 24 hours; that the War Department proceed at the earliest practical date with the construction of this nitric acid plant, contingent upon satisfactory arrangements with the General Chemical Co. for the construction of the accompanying ammonia plant; that negotiations be opened with the Nitrogen Products Co. for the right to use its patents, and in addition, to proceed with experiments, having for their object the development on an industrial scale of the Bucher process for the production of ammonia through cyanide and—in event of satisfactory negotiations being consummated—that a sum of not over $200,000 be allotted for this purpose out of the nitrate-supply appropriation.

In accordance with these recommendations, the Secretary of War, on July 13, 1917, authorized the Chief of Ordnance to enter into negotiations with the General Chemical Co. and the Nitrogen Products Co. in connection with the construction of plants and the use of the processes of these companies.

On July 25, 1917, the Chief of Ordnance, by Office Order No. 25½, established the Nitrate Division under Lieut. Col. J. W. Joyes, to handle all matters pertaining to the subject of nitrogen fixation, including the program recommended by the Nitrate Supply Committee, and to control the expenditure of $3,900,000 of the sum appropriated by Congress and such other funds as might be specifically assigned to it, for carrying out this program.

PLANT CONSTRUCTION AND OPERATION IN UNITED STATES.

Under the direction of this division three plants were built for the fixation of nitrogen; one by the synthetic ammonia process of the General Chemical Co., one by the sodium cyanide process, and one by the cyanamid process. Construction of two other plants was begun but later discontinued.

UNITED STATES NITRATE PLANT NO. 1.

In accordance with the recommendations of the Nitrate Committee, a contract dated September 30, 1917, was entered into with the General Chemical Co. for the construction of a plant to be known as United State Nitrate Plant No. 1 for the production of ammonia by that company's process, and for the transfer to this plant of all orders for building material, apparatus, etc., which the company had intended to use in the construction of a plant of its own. The output was to be used in the manufacture of explosives during the war, and later to be used for agricultural purposes.

Sheffield, Ala., was selected as a suitable location for the plant, because of its distance inland, precluding the possibility of foreign attacks; because of its proximity to extensive coal fields, simplifying the problem of coke and coal supply, and because of its nearness to the center of agriculture, facilitating distribution of its products in peace times.

Construction was begun October 8, 1917, and the plant was practically completed at the time of the signing of the armistice. The general design of the process was placed in the hands of the General Chemical Co. under supervision of the Ordnance Department. Engineering and construction work on the power station and the various buildings, including temporary and permanent buildings for housing employees was done by the J. G. White Engineering Corporation.

The plant consists of four principal parts—the synthetic ammonia plant, the ammonia oxidation plant, the ammonium nitrate plant, and the nitric acid concentrating plant.

The synthetic ammonia plant was built according to design furnished by the General Chemical Co., and the construction and initial operation were carried out with the company's cooperation. It consists of three units with a total capacity of 60,000 pounds of ammonia per day. Only one unit, however, was put in operation.

The ammonia oxidation plant was built to oxidize daily about 30,000 pounds, or one-half of the ammonia produced, to nitric acid, the latter to be used in the neutralization of the ammonia to produce ammonium nitrate. The converter was designed through the co-operation of representatives of the Ordnance Department, the Bureau of Mines, and the Solvay Process Co., of Syracuse, N. Y. The towers and acid system were designed and installed by the Chemical Construction Co., of Charlotte, N. C. The plant, while satisfactory as far as it has been tried out, has never been operated to capacity.

The ammonium nitrate plant is similar in design to numerous other ammonium nitrate plants in this country and has given entire satisfaction as far as it has been tried out.

The nitric acid concentration plant, designed and built by the Chemical Construction Co., Charlotte, N. C., has a capacity of 24,000 pounds of 100 per cent nitric acid per 24 hours. This plant, however, has not been tested.

The process used at the plant for the production of ammonia is known as the Haber process. As modified by the General Chemical Co. the various stages are as follows:

(*a*) The formation of water gas by the decomposition of steam by highly heated carbon in the form of coal or coke. This gas contains carbon monoxid, carbon dioxid, hydrogen, and nitrogen.

(*b*) The conversion of the carbon monoxid to carbon dioxide under the influence of a catalyst.

(*c*) Removal of the carbon dioxid by dissolving in water under a pressure of 100 atmospheres.

(*d*) Removal of the last traces of carbon dioxid by caustic soda.

(*e*) Removal of the last traces of carbon monoxid by hot caustic soda, leaving only the hydrogen and nitrogen. This stage was later modified by eliminating the use of hot caustic soda which had a deleterious effect, owing to its corrosive properties, and substituting a catalytic agent.

(*f*) Combination of the nitrogen and hydrogen under a pressure of 100 atmospheres and at a temperature of 500° to 600° C. to form ammonia.

When put into actual operation, some of the minor details of the process were simplified, but in general the method has remained the same.

The plant, while practically completed, had not actually come into operation at the time of the signing of the armistice, and had not turned out any appreciable quantity of ammonium nitrate up to January 1, 1919, the first being produced on November 12, 1918.

UNITED STATES NITRATE PLANT NO. 2.

In the summer of 1917, the seriousness of the submarine warfare brought to the attention of the Ordnance Department the great need for a further source of supply of nitric acid. The Nitrate

Division recommended the cyanamid process as requiring less electrical power than the arc, and being the only other process that has been developed in this country on a commercial scale.

Consequently on November 16, 1917, a contract was made with the American Cyanamid Co., which had been employing this method, for the construction of a plant at Muscle Shoals, Ala., where the essential raw materials—coal, coke, and limestone—were easily obtainable, and where power could be conveniently obtained from the Alabama Power Co.'s system, pending the construction of a dam in the Tennessee River, at Muscle Shoals, which would be a source of cheap power, later, for commercial production.

This plant, known as United States Nitrate Plant No. 2, was constructed by the Air Nitrates Corporation, a subsidiary of the American Cyanamid Co., for the United States Government, and has a capacity of 110,000 tons ammonium nitrate per year, six times the capacity of United States Plant No. 1.

Construction work on the necessary buildings for the process was done by Westinghouse, Church, Kerr & Co. The power station was designed and constructed by the J. G. White Engineering Corporation. Some delay in construction was encountered, owing to the extremely severe winter of 1917–18, difficulty in obtaining a part of the equipment, and in providing housing facilities for the hundreds of men employed in the construction work. The six units have been practically completed, however, and one unit has been tried out with satisfactory results.

Calcium carbid is the basic material from which the cyanamid is produced and is well known in many chemical industries. The various stages used in the cyanamid process are as follows:

(*a*) Production of calcium carbid by heating together in an electric furnace, coke and calcium oxide, the latter being obtained by calcining calcium carbonate (limestone).

(*b*) Conversion of calcium carbid to calcium cyanamid by exposing at a red heat to nitrogen obtained by first liquefying air and distilling the nitrogen therefrom, according to the Linde method.

(*c*) Production of ammonia by heating the calcium cyanamid with steam.

Part of the ammonia is oxidized in the presence of a catalyzer to nitric acid, while the other part is used to neutralize this acid to produce ammonium nitrate. There is required a power of approximately 2.5 horsepower years per ton of nitrogen converted to nitric acid per annum.

Ammonium nitrate was first produced at the plant on November 25, 1918, less than a year from the beginning of construction, and while the plant had been run on an experimental basis only up to

January 1, 1919, approximately 190 tons of ammonium nitrate had been produced. Nitric acid produced up to that time was about 1,800 tons.

UNITED STATES CHEMICAL PLANT, SALTSVILLE, VA.

After several months' study of the sodium cyanide process as developed by the Nitrogen Products Co., and in accordance with the recommendations of the Nitrate Committee, negotiations were entered into during the fall of 1917 with that company for the use of its patent rights to the Bucher process, and a plant known as the United States Chemical Plant was constructed at Saltsville, in southwestern Virginia, for the production of sodium cyanide for trench-warfare purposes.

This plant was constructed under the supervision of the Bureau of Mines for the Ordnance Department and with funds from an Ordnance Department appropriation. It was practically completed at the time of the signing of the armistice. It is capable of producing 10 tons of sodium cyanide per day by the Bucher process.

The cyanide process uses as its raw materials sodium carbonate, coke, iron, and pure nitrogen, and is somewhat similar to the cyanamid process. To obtain nitric acid by this method the various stages are as follows:

(*a*) Formation of sodium cyanide by heating a mixture of sodium carbonate and coke with finely divided iron in a stream of pure nitrogen to a temperature of approximately 1,000° C.

(*b*) Conversion of sodium cyanide to ammonia by decomposition with steam.

(*c*) Conversion of ammonia to nitric acid by oxidation in the presence of a catalyzer.

In this process the iron is always recoverable and if the conversion of cyanide to ammonia takes place under favorable conditions, the sodium carbonate may also be recovered. Electrical power is not necessary, the requirements being about the same as for the Haber process.

The plant, after completion, was given a trial run by the Chemical Warfare Service and closed, pending a decision as to its final disposition by the Ordnance Department.

UNITED STATES NITRATE PLANTS NOS. 3 AND 4.

After this country had been at war for some time, the need for additional supplies of nitrates became apparent, and at the recommendation of the Nitrate Committee the construction of two other plants for the production of ammonium nitrate by the cyanamid process was undertaken. A contract was made with the Air Nitrates

Corporation and the American Cyanamid Corporation, June 8, 1918, for the erection of these plants—United States Nitrate Plants Nos. 3 and 4, at Toledo, Ohio, and at Ancor, near Cincinnati, Ohio, respectively—each plant to have a capacity of 55,000 tons of ammonium nitrate per year. These locations were selected because of the availability of the electric power required. Construction was about one-fourth completed at the time of the signing of the armistice, at which time work was discontinued because of increased facilities for obtaining nitrates from Chile, the accumulation of sodium nitrate and explosives in this country, and the existing conditions with regard to the war.

A decision has not as yet been reached as to the ultimate disposition of the nitrate plants which were completed, but it has been suggested that they be kept in operation on a commercial scale in order that the processes be thoroughly developed, and while supplying the public with materials necessary to agriculture, yet at small cost and without loss of time be able to furnish nitrates for explosives in case of emergency.

CHAPTER III.

DEVELOPMENT OF EXPLOSIVES.

In order to meet the requirements for enormous amounts of explosives it was necessary to not only produce in large quantities the high explosives authorized for military use, but to develop new types and to carry on various experiments and investigations to this end. Credit should be given the colleges, manufacturing establishments, and individuals who aided the Ordnance Department in this great work. The cooperation of other branches of the Government is also to be appreciated, for it was through these sources that much information was received by this department, tending toward the development of explosives and explosive materials.

There are two classes of military explosives—the propellants, which include black and smokeless powders, the latter including both small-arms powders and cannon powders, and the high explosives, which include those explosives used as bursting charges for shell, grenades, bombs, torpedoes, mines, etc., and those which are used as detonating, priming, and booster materials, for initiating and transmitting the explosive wave to the main charge.

EXPLOSIVES IN USE PRIOR TO 1914.

PROPELLANTS.

At the time of the outbreak of the war in 1914, both the Army and the Navy were using and are still using the standard service nitrocellulose powder for both small arms and cannon, except .45 caliber automatic pistol powder.

This service powder is a pure nitrocellulose powder except for the addition of a small amount of a stabilizer-diphenylamine. Small-arms powder has incorporated with it a small amount of graphite.

The standard .45 caliber automatic pistol powder was "Bullseye," made by the Hercules Powder Co., and was approximately 40 per cent nitroglycerin and 60 per cent nitrocellulose.

In 1913 and 1914 the Navy's requirements were being supplied by private manufacturers and by its powder factory at Indianhead, Md., while the Army was being supplied exclusively by its factory at Picatinny Arsenal. It may be judged how small the Army requirements were, from statements in the report of the Chief of Ordnance in 1914 to the effect that the powder factory at Picatinny

Arsenal had been working at one-half its full capacity and produced a total of 1,255,000 pounds during the year.

Notwithstanding the fact that owing to restrictions in the Army appropriation bills for 1913, 1914, and 1915 preventing the placing of any orders with private manufacturers for the manufacture of smokeless powder, the producing capacity for smokeless powder in this country was about 1,200,000 pounds cannon powder and 50,000 pounds small-arms powder per month.

As an indication of the development of the smokeless-powder industry in this country, it may be noted that in 1914 the total production of all establishments, including those owned by the Federal Government, was 12,684,000 pounds, while in 1909 it was only 6,315,000 pounds per year.

Black powder has been for many years and is still used for military purposes, chiefly as an ignition charge for all cannon powder. Some grades were used for saluting purposes, for pellets, fuzes and primers, and for loading the time rings of combination fuzes. Great quantities of black powder were, therefore, never produced for service, although the plant capacity was always sufficiently great because of the extensive use of black powder as a sporting powder and for blasting purposes. In 1914 the Army was requiring black powder at the rate of only 5,000 pounds per month. It was not found necessary even during the war to increase the black-powder producing capacity.

HIGH EXPLOSIVES.

Before the beginning of the European war, practically the only military high explosives in use in this country were military guncotton, Explosives "D," and trinitrotoluol (T. N. T.).

Military guncotton, a nitrocellulose of high nitrogen content, was used chiefly by the Navy for mines and torpedoes.

Explosive "D" was used as a shell filler by both the Army and the Navy. This material, by reason of its stability, power, and insensitiveness, proved very satisfactory, particularly under conditions prevailing at the time.

In 1907 T. N. T., then a comparatively new explosive, was tested by the Ordnance Department and it was found that under ordinary conditions T. N. T. was slightly less powerful than picric acid and slightly more powerful than Explosive "D," except when the latter was initiated with picric acid. It was also found that T. N. T. was somewhat more sensitive than Explosive "D" and gave a higher density.

As a result of later research, T. N. T. as a shell filler was found satisfactory as to detonation strength and apparently so as to hygroscopicity, but would not stand impact against armor plate. It was also thought to be easier to load and cheaper to produce than Explosive "D."

Further tests were carried on in 1910 and 1912, with the final result that on November 26, 1912, crystalline (pressed) T. N. T. was adopted as the bursting charge for all mobile artillery shell, because of its low cost, the ease and safety with which it could be handled, and because its fumes on detonation were less deleterious than those of Explosive "D."

The principal detonating ingredient in use before 1914 was mercury fulminate, which was used to initiate the explosion of the high explosive (Explosive "D") loaded in the shell. At that time the service high-explosive shell was that known as the "base fuzed" shell; that is, the fuze was at the base of the shell, and the detonator consisted of straight fulminate of mercury. Fulminate was also used in delay action primers for base fuzed shell.

For the purpose of igniting the black powder ignition charge which in turn ignites the propellant powder, compositions of antimony sulphide, potassium chlorate, sulphur, and ground glass were and still are used for friction primers, and guncotton for electric primers.

In 1899 the use of mercury fulminate had been abandoned in small arms percussion compositions, and a composition of potassium chlorate, antimony sulphide, and sulphur substituted.

DEVELOPMENT OF THE ART OF EXPLOSIVES, 1914 TO 1917.

The development of the art of explosives in this country from the time of the beginning of the European war until the time this country entered the war was, for the most part, more in the nature of an adaptation of explosives already known to new uses, with improvements, of course, in methods of manufacture, than the discovery of new explosives.

PROPELLANTS.

No change took place in the type of powder used from 1914 to 1917, but improved methods were adopted in the manufacture. This refers especially to the drying methods.

Up to the fall of 1916 United States Army smokeless powder was all made in accordance with specifications which provided for the air drying of the powder. The drying had to be very slow at first and progressed more rapidly toward the end of the drying period.

This method required a long drying period, from about 26 days for .30-caliber powder to 156 days for 16-inch gunpowder. Not only were the fire hazards great, since large quantities of powder were kept at comparatively high temperatures in the dry houses for rather long periods of time where local over heating was possible, but the space required for a plant practicing this drying method was enormous, as a great number of dry houses were necessary for any great producing capacity and since these houses were used for long periods. In order, therefore, to speed production the commercial powder companies had adopted for their orders for the French Government a so-called "water-dry" process, which had been for a number of years in successful use in France, which country also has a nitrocellulose service powder. This practice resulted in a great saving of time, expediting delivery of powder from 75 to 100 days, as well as reducing the fire risk.

This water-drying method was virtually adopted by the Army early in 1917 and the greater portion of powder having a web up to 0.1-inch subsequently ordered was made using this method. Water-dried powder is, so far as experience to date shows, equal in every respect to air-dried powder.

In manufacturing powder for the French and British Governments, denatured alcohol was used with satisfactory results. This was 95 per cent ethyl alcohol and contained 0.5 per cent benzene. Its use was, therefore, not as closely supervised by the Internal Revenue Department and it was sold to manufacturers at practically the same price as tax-free alcohol. This experience subsequently led to a revision of our smokeless-powder specifications permitting the use of denatured alcohol.

A so-called "sliverless" powder was developed at Picatinny Arsenal under patents granted to Lieut. (now Col.) James L. Walsh. In order to avoid the triangular splinters produced in the powder grain as it burns, a powder grain having a corrugated exterior was designed for use in 12-inch mortars, and some of this powder was made by contractors for the Army.

Owing to a possible shortage of cotton, suitable substitutes for cotton linters were sought by manufacturers.

It has been customary to use only first cut cotton linters in the manufacture of nitrocellulose for smokeless powders for the Army, subsequently second and third cut linters were used and finally as we entered the war it was found necessary to mix hull fiber with the linters in order to meet requirements. Other sources of cellulose were, therefore, investigated. The most promising of these were wood pulp and suitably prepared cotton waste. As a result of these investigations powder specifications were revised to permit the use of spun as well as unspun cotton, and later (September, 1918) to permit the use of cellulose prepared from coniferous woods. While most of this research was conducted subsequent to the entry of the United States into the war, private manufacturers investigated the treatment of cotton waste for preparation of nitrocellulose for powder for the British Government.

HIGH EXPLOSIVES.

During the period from the beginning of the war in 1914 up to April 6, 1917, this country benefited by the experience of the Allied Governments. Up to this time Explosive "D," military guncotton, and T. N. T. were the only service high explosives in use.

In the Army, Explosive "D" was used largely for shell for seacoast fortification guns, while in the Navy it was authorized for all armor-piercing shell, being more insensitive to impact than T. N. T., allowing the shell to pierce the armor plate before detonating.

In 1914–15 orders for only 610,000 pounds of T. N. T. were placed by the Army, for while it had been adopted in 1912, no great quantities had been required. T. N. T. is made by methods elsewhere referred to, from toluol, the production of which was about 7,100,000 gallons in 1916; this capacity being increased in 1917 to 10,000,000 gallons.

Shortly after the beginning of the war, this country, realizing the importance of sodium nitrate, commercially known as "niter" or "Chile saltpeter," as a raw material in the explosives industry, began placing orders for a large supply of this material, which is used in the manufacture of nitric acid and nitrates. In 1914, 1915, and 1916 orders for 5,400,000 pounds were placed.

The national defense act of June 3, 1916, authorizing the Secretary of War to investigate the situation with respect to the production of explosives and ammunition in the country, was the first important congressional legislation paving the way for increased production of ordnance material. In this same year larger appropriations were made for increasing the reserve supply of sodium nitrate and the national defense act carried an appropriation of $20,000,000 for a nitric acid plant. A committee was also apointed from the membership of the National Academy of Science and the American Chemical Society for consideration of the subject of manufacturing nitric acid by a process which would not involve dependence upon a foreign source of supply; in other words, for a process for the fixation of atmospheric nitrogen. The development of this problem has been taken up under the heading of "Fixation of atmospheric nitrogen."

Practically no change in the type of detonating explosives took place during the period 1914 to 1917, except that tetryl and tetranitroaniline were investigated by the department for use in loading boosters.

DEVELOPMENT OF EXPLOSIVES SINCE 1917.

Immediately on the entrance of the United States into the war, active preparations were undertaken not only to increase production of explosives already adopted and in use, but to develop new types, to improve and reduce the cost of their manufacture and to adopt new types which had already been successfully developed by the Allied Governments. The magnitude of this undertaking will be appreciated when it is considered that not only must our own requirements be met, but the requirements of our Allies must also be maintained.

While the producing capacity for propellants, high explosives, and raw materials entering into their production had been materially increased by purchases made in the United States by the Allied Governments, this capacity had to be increased manyfold. The construction of 53 explosives plants, at an estimated cost of $300,000,000, was undertaken to supply the requirements, a very large part of the construction being completed and in an efficient state of operation when the armistice was signed.

It was also necessary to develop new propellants for new types of guns that came into use. Besides this work, extended research was conducted on a number of materials with a view to their use, all of which will be discussed under the subjects of raw materials, propellants, high explosives, and miscellaneous developments.

RAW MATERIALS.

It was necessary to greatly increase the supplies of sulphuric acid, nitric acid, ammonia, toluol, phenol, caustic soda and to provide a suitable substitute for cellulose, in case the shortage of cotton should render its use necessary. Practically no serious difficulties were encountered in meeting the requirements of any of the raw materials except toluol and cotton, the problem of meeting requirements of the former being one of great magnitude.

While the estimated requirements for cotton linters were practically equaled by the supply, it was found advisable to request the Quartermaster General of the Army to refrain from specifying cotton linters as a stuffing for mattresses purchased for the Army. Request was also made of the War Trade Board asking that the exportation of cotton linters be stopped, unless the concurrence of the Ordnance Department and the Council of National Defense was secured. Close cooperation was secured from both the Quartermaster General and the War Trade Board, with the result of conserving for the manufacture of smokeless powder a quantity of cotton linters which may be roughly estimated at between 50,000 and 100,000 bales (500 pounds each).

The greatest problem in increasing raw materials lay in toluol, the basic raw material from which T. N. T. is made. Prior to the war the sole source of this material was from by-product coke ovens. It was, therefore, necessary to develop and adopt new methods of manufacture. The Ordnance Department arranged for the construction of additional by-product coke ovens by a number of the large steel companies with private capital, contracts being awarded for the purchase of the product to secure return on the investments. Arrangements were also made by the department to construct at Government expense 320 additional ovens.

In the summer of 1917 investigations were begun by the Ordnance Department on stripping illuminating gas and the recovery of toluol therefrom, and as a result, contracts were made with the gas companies of several large cities for the erection of gas stripping plants.

Many processes for the production of toluol by the cracking of crude oils or petroleum distillates were investigated by the department and three were officially approved and contracts awarded for their operation.

The plant of the General Petroleum Co. at Los Angeles, Calif., used a two-stage cracking process. The distillate from California crude oil is first freed from gas tops and coke in a continuous still. The clean distillate is then cracked at 1160° F. by passing it through long tubes set in a furnace. This product is again distilled to remove gas tops and coke and the fraction between 100° and 250° C. is saved; the by-products are gasoline and fuel oil. The fraction saved is again cracked at 1160° F. and toluol obtained by distillation in an intermittent steam still.

In the Hall process operated by the Texas Oil Co. at Bayonne, N. J., the clean petroleum distillate is cracked under 80 pounds pressure at 700 to 750° C. in a coil of steel tubing 600 feet long. The vapors are led through air condensers where free carbon and tarry and pitchy constituents are removed. The uncondensed vapors are then condensed by water cooling and fractioned to obtain toluol.

In the Rittman process at the Synthetic Hydrocarbon Co., Pittsburgh, Pa., solvent naphtha is preheated and converted into a gaseous state. This is sprayed into the cracking tube. The products are passed into expansion tanks, where the carbon settles out, then through air condensers and finally into separating tanks, where the oil is drawn off. One of the features of this method is the use of chains mounted on a rotating vertical rod, the chains swinging out and wiping the sides of the cracking tube.

Phenol is the basic raw material from which picric acid is made, the latter being used for the manufacture of Explosive "D." Large quantities of picric acid were also made in this country for the

French Government, both on contracts from the French Government and on contracts by the Ordnance Department for the purpose of repaying purchases of ammunition and guns from the French Government. Picric acid is made chiefly by the sulphonation of benzene. Benzene sulphonate is treated with calcium carbonate to produce calcium benzene sulphonate, which in turn is treated with sodium sulphite and a small amount of sodium carbonate, producing sodium benzene sulphonate. The latter is then fuzed with caustic soda to produce sodium phenolate which in turn is treated with carbon dioxide to produce phenol.

The additional requirements for sulphuric acid were met by the erection of both chamber and contact plants in all high-explosive plants built for and under the direction of the Ordnance Department. At the beginning of the war both pyrites and sulphur were used, the pyrites coming from Spain. On account of submarine warfare, importations ceased and the sulphur deposits in Texas and Louisiana were depended on.

The submarine also had the effect of lessening importations of sodium nitrate from Chile used for the manufacture of nitric acid, hence the investigations in regard to development of processes for the fixation of atmospheric nitrogen, referred to elsewhere in this report.

Duriron, as a substitute for lead, came into extensive use in sulphuric acid plants, with the result of a considerable saving in cost.

PROPELLANTS.

When the United States entered the war, the capacity was about 5,000,000 pounds per month for smokeless powder of all granulations, and the indications were that this capacity would need to be greatly increased. The construction of two of the largest smokeless-powder plants in the world was, therefore, undertaken under the direction of the Ordnance Department; namely, that at Nitro, near Charleston, W. Va., and that near Nashville, Tenn., the latter being known as "Old Hickory," taking its name from the nickname of Andrew Jackson, whose old home, "The Hermitage," was near the site of the plant.

Not only were plant facilities increased but methods were also developed for speeding the powder-drying process. In addition to the water-drying system which was adopted in 1917, another system of drying was investigated and most promising results attained. This method was known as the alcohol-dry system, and was devised by Mr. Nash, of the Hercules Powder Co. The great recommending feature of this method is the extraordinary short time required for drying powder.

The present practice is to use enough alcohol containing a small percentage of diphenylamine and to circulate it through the powder at a temperature not exceeding 50° C. until the ether is virtually all removed. This requires from five to six hours. The powder is then washed with cold water and surface dried. The principle of the method is the ready solubility of ether in alcohol and in turn the easy solubility of alcohol in water.

The powders dried by this method have been fired with excellent results. They have also proven satisfactory in chemical and mechanical tests, and thus far have given good surveillance tests. A 12-inch seacoast-gun powder was in 65.5° C. surveillance magazine 270 days without failure; a standard powder of corresponding web is only required to give 137 days' test.

The modifications in the cannon powder specifications with regard to the use of denatured alcohol were also incorporated in the small-arms specifications.

Until the fall of 1917 all powder used for small arms was that known as .30 caliber Pyro D. G., but owing to the development of a great number of types of ammunition this powder did not meet all the conditions and therefore other types had to be developed and adopted; it was also clearly evident that the possible granulation capacity for Pyro D. G. powder in this country could not possibly meet the requirements for .30 caliber powder and it was, therefore, imperative that other types of powder suitable for use in small arms be adopted. As a result, the small-arms specifications were enlarged to cover I. M. R. No. 22, I. M. R. No. 34, I. M. R. No. 17, and I. M. R. No. 23.

It was found, too, that some of the powder known as "Bullseye" and used for the .45 caliber automatic pistol, possessed a serious fault, namely, that on account of its high density, shells could be double loaded and be assembled without this double loading being detected. A powder known as "Pistol Powder No. 3" was brought forward as a substitute for "Bullseye" and was adopted.

I. M. R. No. 22 and No. 34 which vary slightly from Pyro D. G. in size and nitrogen content of the nitrocellulose used in their manufacture, but meet the ballistic requirements laid down for .30 caliber model 1906 and 8-millimeter Lebel ammunition, were adopted to help meet the small-arms requirements.

I. M. R. No. 17 is a coated powder developed by the Du Pont Co. to meet the requirements laid down for the English and Russian small-arms ammunition. This is a powder which has been rendered more progressive than an ordinary single perforated grain by surface treating with a material which renders the surface partially fireproof. In order to partially compensate for the slowing down of the powder, the nitrogen content of the nitrocellulose used in its manufacture has been increased; in other words, a nitrocellulose with a higher degree of nitration has been used. In this way a powder has been produced from which normal velocity can be obtained with approximately the same charge as with Pyro D. G. This powder has been found suitable for use in .30 caliber ammunition and 8 millimeters and was therefore adopted.

I. M. R. No. 23 powder is manufactured by the Du Pont Co., but its use was discontinued because it was found inferior to Pyro D. G., giving erratic pressures, greater erosion, and greater muzzle flash.

Powders of suitable web thickness were developed for the following new types of guns and howitzers: 75-millimeter French, model 1897; British 18-pounder, known as model 1917; 4.7-inch field gun, model 1917; 4.7-inch anti-aircraft; 4.7-inch howitzer; 5-inch wheel mount; 6-inch wheel mount; 155-millimeter Filloux gun; 155-millimeter Howitzer (Schneider model); 155-millimeter howitzer (Bethlehem model); 8-inch gun, railroad mount; 8-inch howitzer, Mark I–VI and Mark VII; 9.2-inch howitzer, Mark I and Mark II; 10-inch seacoast gun, model 1888, Mark I and Mark II, modified for railroad mounting; 12-inch seacoast gun, model 1895; and 12-inch seacoast mortar, model 1890, Mark I–1908, also modified for railroad mounting; Chilean gun, similar to 12-inch 50-caliber Navy, Mark VII; 14-inch railway mount; 14-inch 50-caliber Navy gun, model 1920; and 16-inch howitzer.

In developing powders for new types of guns, it was found that for some a powder having nitrogylcerin in its composition was most satisfactory. I. M. R. No. 31, a nitroglycerin powder, which had been purchased by the British Government, was found to be the best powder for the 37-millimeter model 1916 gun, firing a low-explosive shell weighing 17½ ounces, which was adopted from the French. But as these guns were to be used in tanks and other confined places, it was not considered desirable for use, as powders with a nitroglycerin base give, on combustion, a very high percentage of carbon monoxide. This powder was therefore eliminated. The .30 caliber Pyro could not be considered for this use on account of the limited capacity for production available, and therefore I. M. R. No. 17 was adopted, although it did not fulfill the requirements in an ideal manner.

Not only was it necessary to develop new types of powder, but in view of the possible shortage of cotton, it was necessary to find a suitable substitute for cotton linters. The most promising of the materials investigated was wood pulp, which had been successfully used in Germany in the manufacture of nitrocellulose. By the fall of 1918 sufficient progress had been made to warrant our specifications being so drawn as to cover the use of specially prepared wood cellulose. In fact, powder had been made from a blend of 50 per cent wood cellulose and 50 per cent cotton cellulose for 75-millimeter gun. This powder was found to be equal to any 75-millimeter powder manufactured from straight linters.

The War Department research was carried on at Picatinny Arsenal, where wood pulp was prepared by the sulphate, sulphite, and soda treatments. The Du Pont Co. had started a series of similar investigations in cooperation with the Forest Products Laboratory of the Department of Agriculture, Madison, Wis.

As a result of this research work, it was definitely agreed that wood pulp prepared from coniferous woods by either the soda, sulphite, or sulphate process is entirely suitable and satisfactory for nitration purposes. The most satisfactory physical form in which it can be prepared is either in the form of a crêpe tissue or in the form of loose sheets of semiblotting paper. The use of wood pulp offers the following advantages:

(1) Its low cost.
(2) Saving in manufacturing operations.
  (*a*) Not necessary to dry or pick.
  (*b*) Not necessary to run through beaters or Jordan engines in order to reduce to pulp.
  (*c*) Requires approximately 15 per cent less solvent for colloiding purposes.
(3) Preparation from what are now waste materials.
(4) Its unlimited supply.

Spun fiber was also investigated. The Ordnance Department specifications for smokeless powder prohibited the use of spun cotton for its manufacture. The Navy Department, on the other hand, had always permitted its use. Investigations were conducted at Picatinny Arsenal on cellulose prepared by treatment of rag waste, which had been used with success by manufacturers as well as by the Navy. As a result, in August, 1918, the word "unspun" was eliminated from the Army specifications. It was, of course, necessary that the cellulose meet the specifications in other respects.

Another matter relating to the development of propellants required considerable investigation. The flash produced at the discharge of large-caliber guns is such as to be visible oftentimes for many miles. The disadvantages of such a condition are obvious, as the developments in flash ranging have been such as to enable the exact location of a gun to be determined from its flash.

The French and Germans had apparently, prior to 1914, realized the necessity of reducing the flash, and the Germans attached so much importance to their achievements in this direction that every effort was made in prewar times to keep the knowledge of their results from all noncommissioned officers and enlisted men. Just what success was had by the French is not known.

While some flashless firings had been conducted at Sandy Hook Proving Ground in 1909–10, using an English composition and later a compound developed at Picatinny Arsenal, this work was not pushed to any extent until after April 6, 1917.

Several materials were investigated for use as flashless compounds, those giving the most satisfactory results being oxanilid used either alone or mixed with such substances as shellac, glue, gum arabic and collodion, acetanilid, dinitro-oxanilid with mononitro naphthalene and rosin as binders, and rock salt alone and mixed with black powder.

Oxanilid was found to be the best agent for use with field ammunition to produce flashlessness. Its action is certain and it can be depended upon to reduce the flash at least 95 per cent. There were numerous instances where an entire extinction of the flash was obtained by its use. It was never adopted, however, owing to its excessive cost, the difficulty in obtaining the raw materials for its manufacture in war times, the presence of suffocating fumes after using, the necessity of using an increased charge of powder, and the difficulty of field supply.

For separate loading ammunition the most suitable material was found to be sodium chloride in the form of rock salt. Its flash-reducing effect is splendid; it is cheap, easily procurable anywhere, and requires no special shipping container. If the necessity should arise, it can be used loose in the gun; that is, thrown into the chamber by means of a scoop, though it was felt that a silk bag should be used, as under some conditions it would not always be practical to introduce the salt in loose form.

The use of rock salt was authorized in the 6-inch gun, 155-millimeter, 8-inch, and 9.2-inch howitzers. At the time of the authorization it was thought necessary to use the salt mixed with black powder, since it had never been tried without it. Later tests showed that equally good, if not better, results were obtained without the addition of black powder.

For black powder no increase in capacity for production was necessary or change in types, the only change being the elimination of ballistic tests, acceptance of the powder being based on chemical inspection. The capacity for sporting and blasting powder was utilized to a great extent for the manufacture of those grades needed for military purposes.

There are three grades of black powder: A, B, and C, each grade being subdivided into several granulations. Grade A is specified for igniting charges, bursting charges of shell, base charges of shrapnel, and for the manufacture of primers and fuzes; Grade B corresponds to high-grade commercial blasting powder; Grade C is a special high-grade powder used in the manufacture of the time-train rings of fuzes.

All grades have the same composition, namely:

Potassium nitrate	74.0
Carbon (wood charcoal)	15.6
Sulphur	10.4

Variations from the above percentages not to exceed 1 per cent are permitted.

The charcoal and sulphur are pulverized in a ball mill and then mixed with hot saturated solution of the potassium nitrate. The mass, when cool, is then incorporated in a wheel mill. After being removed from the wheel mill, it is pressed into a solid cake by a hydraulic press. The cake is then broken up and crushed in a corning mill. The powder is then polished, dried, and glazed in one operation in a rotating drum. It is then sorted and packed.

HIGH EXPLOSIVES.

The following new high explosives were authorized: Amatol, sodatol, trinitroxylol (adopted only by the Navy), tetryl, tetranitroaniline, nitrostarch explosives, and lyconite.

The most important of these was amatol, which had been developed to a most satisfactory stage by the British in their search to find a shell filler which could be used instead of straight T. N. T., realizing, as they did, that a possible shortage of T. N. T. was imminent.

A board of officers investigated among other subjects the manufacture and use of amatol as a shell filler. In connection with this, Col. C. T. Harris, jr., as head of the board, made a special trip to England in the fall of 1917.

This board recommended for mobile artillery high explosives shell:

(*a*) Three-inch field gun and 75-millimeter and shell of lesser caliber, first, 50/50 amatol; second, T. N. T.

(*b*) All shell larger than 3 inches in caliber, except base fuzed shell 10-inch caliber or greater, for seacoast guns or railway carriages for land service, first, 80/20 amatol; second, 50/50 amatol; third, T. N. T.

(*c*) Grade I T. N. T. to be reserved for fuzes and boosters.

(*d*) The only substitute for (*a*) and (*b*) then considered feasible was a mixture of 80 parts ammonium nitrate and 20 parts T. N. X.

For seacoast shell the board recommended:

(a) That base fuzed shell 10-inch caliber or greater, for railway mounts be filled with Explosive "D" until such time as amatol be found satisfactory.

(b) That all shell for seacoast guns in the United States be loaded with Explosive "D."

For trench warfare carriers:

(a) For hand and rifle grenades, a suitable nitro-starch explosive.

(b) For trench warfare mortar shell, a suitable nitrostarch explosive. Until such nitrostarch explosives were available, 80/20 amatol was to be used.

For drop bombs:

(a) E. L. 104, afterwards known as lyconite (an explosive containing guncotton, sodium nitrate, and nitro compounds).

(b) Nitrostarch explosive.

(c) Until E. L. 104 or a suitable nitrostarch explosive become available, it would be necessary to use 80/20 amatol.

These recommendations were approved by the Acting Chief of Ordnance and by the Engineering Bureau, April 26, 1918, and immediate steps were taken to carry out the recommendations, not only in regard to the use of the explosives themselves but also in regard to the development of methods for their manufacture and that of raw materials.

Amatol is a mixture of ammonium nitrate and trinitrotoluene. As adopted the proportions were 80/20 and 50/50, the first figure referring to the number of parts of ammonium nitrate and the second figure to the number of parts of T. N. T.

In this country the mixing of the ingredients is done by placing the hot dry ammonium nitrate in a suitable steam-jacketed vessel at 100° C. and then adding the requisite amount of T. N. T. The 50/50 mixture is sufficiently fluid to be poured into the shell and is loaded by the casting method. Smoke mixtures were at first provided for, but later omitted, since the larger percentage of T. N. T. in 50/50 amatol makes the use of a smoke mixture unnecessary. 80/20 amatol is loaded by what is known as the "horizontal extruding machine." The mixture is made in the usual way and transferred to the hopper of the machine, from which it is fed by rotating blades to a worm or screw conveyor, the feeding end of which is inserted in the shell. The shell is mounted on a carriage and is held by means of a counterweight against the conveyor tube. This counterweight insures the proper density of loading (1.40 to 1.45), a most important factor in shell loading. As the shell is filled the carriage on which it is fixed moves away from the machine. A cavity is left in the amatol by the tube of the extruding machine and this cavity is filled with molten T. N. T., which in turn has a similar cavity for the introduction of the booster.

In loading shell with T. N. T., 50/50 amatol, or 80/20 amatol, it is necessary to avoid what is known as cavitation, and to obtain proper density of the material, to avoid setbacks. These problems were successfully solved by the Engineering Division by careful inspection of loading and suggestions of improved operating details.

In pouring T. N. T. a column of the semiliquid mass is made and is known as a riser. This gives more pressure in the material and prevents the formation of cavities. The best temperature of the mass, when poured, was also determined.

In pouring 50/50 amatol a proper temperature was also established.

In loading 80/20 amatol so much difficulty was experienced in obtaining a proper density that it was found necessary as a temporary expedient to increase the percentage of T. N. T. to 30 per cent to speed production.

Much work was done in order to determine the most suitable grades of materials to be used in both 50/50 and 80/20 amatol, and also to eliminate from the ammonium nitrate those impurities which tend to produce frothing of the amatol.

Smoke mixtures were developed for use in shell loaded with 80/20 amatol and are introduced into the bottom of the shell. Ammonium chloride is the principal ingredient.

For the production of amatol it was necessary to study the manufacture of ammonium nitrate and increase the capacity for its production. The usual method of manufacture in this country was the so-called neutralization process consisting of the neutralization of nitric acid by ammonia. When made by this process ammonium nitrate grained at a temperature of 290° to 300° C. was found most suitable. A new process which had been developed to great success commercially in England and known as the Freeth or Brunner-Mond method was adopted by the Ordnance Department. This method consists of the double decomposition of ammonium sulphate and sodium nitrate. A plant for producing ammonium nitrate by this process was built at Perryville, Md. The product was delivered in bulk, as crystals, and contained about 3 per cent moisture. It was highly satisfactory, good densities having been obtained with it from the start.

In the recommendations of the board referred to as having investigated explosives in England, it was stated that sodatol (a mixture of T. N. T. and sodium nitrate) was a possible substitute for amatol. Accordingly, preliminary tests along this line were begun in October, 1917, at Picatinny Arsenal, using amatol as a standard, and in April, 1918, a complete report was submitted, recommending its adoption as an approved shell filler. The grades 70/30 and 60/40 sodatol gave results comparable to those obtained with T. N. T. and amatol; in fact, 60/40 sodatol was superior in both fragmentation and crater tests. This recommendation was approved by the Chief of the Engineering Division, with the reservation that it would not be put in production, but held in reserve to be used if needed. Specifications were prepared and approved September 30, 1918, but were not issued.

Trinitrotoluol, commonly known as T. N. T., proved to be one of the most important explosives used in the war. It is made by nitrating toluol which conforms to specifications with a mixture of nitric and sulphuric acid. In this reaction the sulphuric acid plays no part except to take up the water formed. The nitric acid introduces the nitro radicals into the compound. There are four methods for the manufacture of T. N. T., depending on whether the nitration is accomplished in one, two, or three stages or continuously. Grade I is purified by treatment with sodium sulphite or by recrystallization from specially denatured alcohol. In addition to its use as a shell filler, either alone or mixed with ammonium nitrate, T. N. T. Grade I is also used for loading boosters.

Trinitroxylene, as a substitute for T. N. T., was adopted by the Navy Department in the early part of 1918. While specifications for it and xylene, from which it is made, were drawn up, they have not to date been issued It is prepared by first obtaining meta xylene, by sulphonating crude xylene, which contains all three isomers. The nitration is made in two steps with a mixture of nitric and sulphuric acid, first producing dinitroxylene and then nitrating this to trinitroxylene.

Tetryl or trinitrophenylmethylnitramine was developed for use as a booster charge for high-explosive shell and for use in detonating caps—that is, in shell it is used as an intermediate charge between the fulminate detonator and the main explosive—and since it has a high rate of detonation it insures the complete detonation of the main explosive charge.

It had been used extensively in Europe for this purpose during the war, the United States adopting it as a result of the satisfactory experience with it there. Before the war the United States used it only to a limited extent, the usual explosive for booster charges being T. N. T. On account of the high cost of tetryl it has never come into use as a shell filler.

Tetryl is most commonly made by the dimethylaniline method, which consists briefly of treating aniline with methyl alcohol in the presence of iodine as a catalyzer. The dimethylaniline is sulphonated with sulphuric acid, and the sulphonate nitrated with nitric acid. After purification it is prepared in the form of pellets. Its nitrogen content is high, being 24.4 per cent, and it requires only a small amount of external oxygen to completely oxidize it. Tetryl is regarded as one of the strongest explosives manufactured.

While the Ordnance Department always considered that the use of sodium carbonate in the purification of tetryl was not only unnecessary but inadvisable, in order to increase production its use was permitted, not waiving, however, the requirement that the finished product should contain no sodium salts.

Tetranitroaniline, known as T. N. A., was also adopted for use as a booster explosive. This explosive was invented in 1910 by Dr. B. J. Flurscheim and had been investigated both at Picatinny Arsenal and at the Naval Proving Ground, Indianhead, Md., and as a result its use as an explosive was authorized. T. N. A. is made by nitrating benzol to produce dinitrobenzol, which in turn is reduced to metanitroaniline, the latter treated with sulphuric acid to make metanitroaniline sulphate which is nitrated to T. N. A. T. N. A. has a higher nitrogen content (25.64 per cent) than tetryl and about the same explosive force. It is, however, decomposed by water, the decomposition being more rapid the higher the temperature.

Nitrostarch is the authorized explosive for hand and rifle grenades. While it has been long known as an ingredient of commercial (blasting) explosives; e. g., "Arctic Brand," its sensitiveness and tendency toward instability had delayed its use as a military explosive. The Pennsylvania Trojan Powder Co. has, however, succeeded in making a stable product by a secret process of manufacture and purification.

Nitrostarch is made by the nitration of starch, preferably sago or cassava, but other starches, specially treated, have been successfully used. It is not used alone as an explosive but mixed with other ingredients. One of the advantages of its use as a commercial explosive is that, unlike nitroglycerin, it does not freeze when exposed to low temperatures. Besides this it can be produced at comparatively low cost.

For use in trench warfare the formula of Trojan grenade powder now given in the specifications is as follows:

	Per cent.	
Nitrostarch	25	±2
Ammonium nitrate	33	±2
Sodium nitrate	38	±2
Charcoal	2	± .5
Hydrocarbon	1	± .5
Antiacid	.5	± .3
Diphenylamine	.3	± .1
Moisture, not more than	1.25	

The Du Pont Co. has also developed a nitrostarch powder known as grenite or Du Pont grenade No. 1, which has proved satisfactory in hand and rifle grenades. Its composition as required by specifications is as follows:

	Not less than—	Not more than—
Nitrostarch	95.5	98.25
Petroleum oil	.75	2.00
Gum arabic	.75	2.00
Water		1.00

Other nitrostarch explosives were investigated by the department with a view to their use in hand and rifle grenades and in demolition drop bombs. Among those so tested were Starite, Non-Freezing Powder, and Atlas Nitro Starch Powder.

For use in drop bombs and trench-mortar shell an explosive first known as E. L. 104, and later as lyconite, was developed. Its composition is:

	Per cent.
Water	16
Guncotton	35.5
Sodium nitrate	33.5
Nitro compounds	15

Much experimental work was carried on with lyconite in drop bombs and hand grenades with the result that in April, 1918, it received tentative approval as a filler for Barlow or high-capacity drop-bombs. But in July its use was authorized only until such quantities as were on hand or contracted for were utilized. This was due to the development of amatol as a more satisfactory drop-bomb filler and the inability of lyconite to maintain a constant-moisture content or maintain densities as laid down in the specifications and the variations in the nitro compound used.

Ammonium picrate, known as Explosive "D," and referred to as being recommended for all seacoast guns and base fuzed shell 10-inch caliber or greater for railway mount guns, continued to be used. It is made by ammoniating picric acid. A saturated boiling solution of picric acid is prepared and ammonia introduced into it in the form of a 26° B. solution while the heating and boiling proceeds. The filtered liquor is tranferred to tubs, where it is allowed to cool with agitation, the ammonium picrate crystallizing out. The crystals are freed from the mother liquor in centrifugal machines. Ammonium picrate is yellow in color, but red varieties have been made, the red variety being somewhat more sensitive than the yellow.

Of the detonating explosives, the most important is mercury fulminate, the specifications for which were approved in October, and issued in November, 1917. It is used in percussion cap compositions and in compositions for percussion primers of all fuzes except delay action primers and concussion primers for combination fuzes. It is prepared by the action of ethyl alcohol on a solution of mercury in nitric acid, the reaction usually taking place in a large carboy, the alcohol being gradually added; the fulminate precipitates out. While often used alone, greater efficiency is obtained with a mixture of 90 per cent mercury fulminate and 10 per cent potassium chlorate.

Other explosive materials were also used for compositions for the primers in service; i. e., for friction primers, electric primers, combination electric friction primers, percussion primers, and igniting primers. For friction primers the pellet is composed of a mixture of antimony sulphide, chlorate of potash, sulphur, ground glass, and sometimes a hardened matrix, such as gum arabic. In electric primers guncotton is used as a charge. Formerly percussion compositions of all service primers contained a large part of fulminate of mercury, but owing to the danger involved in handling mixtures containing this material, its use as a primer ingredient in service primers manufactured at Frankford Arsenal has been abandoned and a mixture containing potassium chlorate, antimony sulphide, and sulphur has been substituted.

MISCELLANEOUS DEVELOPMENTS.

Investigations of various explosives which appeared to be promising were carried on. Most of these were in progress at the time of the signing of the armistice, and covered chlorate and perchlorate explosives, anilite, hydrogen, and oxygen as a military explosive, hexanitrodiphenylamine, parazol, nitrated ivory nut, and nitro-aromatic compounds, and also the subject of cartridge-bag substitutes.

Explosives having either a chlorate or perchlorate as an ingredient have been continually suggested, but owing to their great sensitiveness have not been adopted, although progress in their development was made, and before the signing of the armistice both Great Britain and this country had succeeded in overcoming this objection and in obtaining a composition suitable for use in trench warfare.

Anilite, a mixture of nitrogen peroxide and benzol or nitrobenzol, was suggested for use in aero drop bombs, high-explosives shell, hand grenades, low-velocity trench-mortar shell, earth mines, depth bombs, and submarine mines, the ingredients being kept apart until ready for use. Investigations showed that this material might be suitable for drop bombs, and had reached a point where shipment of bombs to France for service test seeemed justifiable.

Development of an electrolytic bomb was undertaken to determine the effectiveness of electrolytic gas as a military explosive to be used in harbor and earth mines, aeroplane and submarine bombs, and as a bursting charge for poisonous gas or high-explosive shell. The principle on which the bomb or shell was based was to have the c partly filled with water, to electrolyze the water into hydroge oxygen, and holding these elements under pressure to explod gases by means of a detonator.

Owing to the information received from the British indicating hexanitrodiphenylamine was a valuable explosive, research was dertaken at Picatinny Arsenal to determine its suitability booster material. It was found to compare favorably with te T. N. T., and T. N. A., although reports of the results were not tained until after the signing of the armistice.

Another explosive on which research was conducted was para which is dinitrodichlorbenzol. No report received to date, howe indicates its superiority over other known explosives.

Experiments on nitrated ivory nut were carried on to determ the value of this material which is the fruit of a tree of the pa species and which is used chiefly in making buttons. There bei much waste in the form of trimmings and dust, it was desired nitrate and use this as an explosive for caps in place of mercury fu minate. Because of its high cost and lack of sufficient supplies of th raw material it was not adopted for use.

Among the nitroaromatic compounds investigated, besides thos already mentioned, were trinitrobenzene, trinitroanisol, and tri an tetra nitronaphthalene. None of these, however, were adopted.

Investigations were undertaken to find a suitable substitute for silk for cartridge bags for powder charges. Cloths had previously been made entirely of noils yarn, a by-product of the spun-silk industry. As a result of extensive research, the use of spun silk was adopted for the warp of the cloth, the extra cost being counterbalanced by the superiority of this material, which has a higher tensile strength, is finer, and produces greater yardage per pound. A direct process was developed also for spinning noils silk from waste. Wool, artificial silk, and cotton, treated to make them flame proof, were also investigated. As a substitute for the cartridge bag itself, nitrotite, a pyroxalin product, was developed to a stage where specifications for it were issued, and 50,000 rounds of ammunition were ordered for shipment to the American Expeditionary Forces.

CHAPTER IV.

PROCUREMENT OF EXPLOSIVES.

After the various types of explosives had been developed to a satisfactory degree, authorized by the Chief of Ordnance and adopted for the Ordnance program, it was necessary, in order that these materials be produced in quantities sufficient to meet the needs of the Army, that negotiations be entered into with the manufacturers of America and contracts made not only for the finished product but for the raw materials as well.

RAW MATERIALS.

The first responsibilities, with regard to the raw materials, were procurements of sulphur, nitrate of soda, sulphuric acid, and phenol, which are most important raw materials for the manufacture of explosives; but the scope of the work was necessarily and rapidly extended to include many other essentials such as nitric acid, alcohol, ammonia, benzol, cotton linters, platinum, etc.

At various times the situation, with regard to some of these chemicals, was very difficult and caused much anxiety. Sulphur (brimstone) was chiefly available from only two mines, and during the summer of 1918 the plant of the largest mine was wrecked by a tornado.

The nitrate of soda required had to be transported from Chile on vessels that constantly risked destruction by storms and submarines.

It was found that out of the whole production of sulphuric acid, estimated at about 4,500,000 tons of monohydrate per annum, such considerable proportion was required for indirect war needs that the Ordnance Department could only command less than 5 per cent of the output.

The capacities for the manufacture of nitric acid were inadequate.

Production of alcohol was largely dependent upon corn and sugar crops.

Ammonia and benzol productions required increase. Platinum was very scarce and the entire world was depending upon productions of Russia and Colombia. But these difficulties were all overcome by contracts for new facilities and by gaining the necessary cooperation from other Government departments.

The volume and variety of materials was extraordinary. Seven hundred and fifty contracts were placed for 1,402,020 tons, 11,458,219 gallons, and 1,363,570 cubic feet of materials, to the total value of approximately $205,000,000. The actual quantities contracted for of the more important raw materials are as follows:

Sulphur	long tons	9,740
Nitrate of soda	do	77,622
Sulphuric acid	do	360,379
Phenol	do	64,000
Nitric acid	do	41,799
Alcohol (ethyl and denatured)	do	16,314
Ammonia	do	10,700
Benzol C. P.	gallons	12,257,030
Cotton linters (raw), approximately	bales	650,000
Cotton linters (bleached), approximately	pounds	43,000,000
Platinum, approximately	Troy ounces	50,000

With the signing of the armistice it was necessary to request suspension or termination of 157 contracts, valued at $42,236,944.31.

FINISHED PRODUCT.

Orders were placed for the following explosives:

- Propellant charges:
  - Black powder.
  - Small-arms powder (smokeless).
  - Sporting powder.
  - Cannon powder (smokeless).
- Booster charges:
  - Tetryl (trinitrophenylmethylnitramine).
  - T. N. A. (tetranitroaniline).
- Shell filler:
  - Ammonium nitrate.
  - Ammonium pictrate.
  - T. N. T. (trinitrotoluol).
  - Grenade powder (nitrostarch).
- Primers and caps:
  - Fulminate of mercury.

Early in 1918 a certain quantity of lyconite, commonly known in Army circles as E. L. 104, was bought, but owing to its uncertain qualities its use was abandoned. There were also contracts for pyro cotton, D. N. B., powder rings, and shotgun shells. While picric acid was not used as an explosive by the United States, very large quantities were contracted for because of its use as a shell filler by Great Britain, France, and Italy, and its manufacture was undertaken as a means of repaying loans or war material obtained from our Allies. A limited amount, however, was used by the United States for the production of toxic gas, the quantity so employed averaging about 500,000 pounds per month. Orders were also placed for cartridge cloth and for cutting and sewing the material into powder bags for propellant charges.

In direct association with the finished explosive, it is necessary to speak of a branch which called for a variety of technical information so far as placing contracts is concerned. This branch contracted for the construction and operation of toluol recovery plants, refining of toluol, purchase of same and the installation of numerous by-product coke-oven plants for production of benzol.

LETTING OF CONTRACTS.

The immediate concern of the Ordnance Department was to utilize to capacity all existing facilities for the manufacture of the various explosives, and at the same time to take measures to enlarge existing plants and determine upon what scale and at what locations new facilities should be created. A ready response on the part of the manufacturers whose plants and machinery were at all suited to the production of explosives was found and many such, by changes more or less great, were converted to explosive manufacture.

Contracts, as a rule, were made on a "fixed-price" basis; this basis being determined from the cost of the components entering into the explosive, which prices were established by the War Industries Board, and the components furnished to the contractor by the Government. Contracts contained a clause that fluctuations in prices or raw materials should provide automatically for a proportionate change in the price of the finished product. During 1918, it was virtually impossible for any contractor to obtain explosive components except through the Ordnance Department, and as explosive prices were based on Government prices for components had the manufacturer been able to obtain raw materials from outside sources, such prices were invariably higher, and the manufacturers' profits would have been converted into a loss.

In addition to the fixed-price contracts, a certain number of contracts were let on a "cost-plus" basis. In such cases, the Government owned the facilities and the contractor acted as agent of the Government, receiving a certain sum over and above the predetermined price based on such operation, but a sliding scale provided that if the cost of the product tended to rise the agent would receive less. "Cost-plus" contracts, however, existed where the contractor was engaged in experimental work in an endeavor to produce a given explosive by a new and commercially untried method. This was particularly true of the production of picric acid by the so-called mono-chlorbenzol process. Throughout the war the only practical production of picric acid was by the phenol process, which is rather wasteful. Not until the requirements of the Chemical Warfare Service for chlorine were thoroughly known, and it was determined that there was a sufficient supply of this gas to meet its needs as well as to divert a certain quantity for experimental purposes, was the new process tried out. While practical, it proved to be very expensive and could only be countenanced under the necessity for production brought about by the emergency.

PROCEDURE IN NEGOTIATIONS.

The manner of negotiating contracts for explosives underwent a certain amount of change as manufacturers became accustomed to manufacture at capacity, with the experience gained in chemical and mechanical efficiency due to the incentive for production, and the opportunities afforded of trying all known methods for expediting deliveries. It is almost paradoxical, but a fact, that notwithstanding the great advance in wages, the increased cost of raw materials, and the absolute necessity which existed for quantity production, the prices of the finished products should show a general downward tendency. This desirable attainment was brought about, in a measure, by the patriotic instincts of contractors who recognized that their very existence depended on coordination of effort and the closest kind of cooperation with the various branches of the Government. As time went on and the struggle in France became acute, the disposition of contractors to waive the matter of profits in their eagerness to assist the Ordnance Department, became more and more marked. More than one contractor has said to the writer, "Here is what it costs me to manfacture. You name the contract price, and I will agree to it."

A good standard for comparison of prices was afforded by the E. I. du Pont de Nemours & Co., whose various plants at all times, expanded as they were to the limit, were running full time and overtime, anticipating deliveries in an endeavor to meet the requirments schedule. It was generally appreciated that an established explosive corporation with the high grade of skilled employees they possess, would be very likely to figure as low as was consistent under the circumstances, with that degree of profit which would enable the manufacturer to take proper measures to safeguard the premises both in respect to explosion and the safety, health, and morals of his employees.

In the later months it was not found that variations from established prices could be great so far as ammonium nitrate and ammonium picrate were concerned. There were, however, very heavy cuts in the prices of smokeless powder and T. N. T., in part due to overcoming inefficient methods through the opportunity to observe where expense could be cut out when operating at maximum capacity.

There was practically at no time any chance of competition in negotiating, due to the fact that virtually all explosive manufacturers were engaged 100 per cent in Government business. A complete list existed of all contractors who manufactured explosives, and when the matter of placing an order became imminent, they were invited to come to Washington and give an idea as to their capabilities, and possibilities of expansion. Every facility for obtaining information regarding machinery and equipment was placed at their disposal, and such other aid given in the way of priorities, as would expedite installation. There was very little "bargaining."

TRACING THE PLACING OF AN ORDER OR CONTRACT FROM THE ESTIMATES AND REQUIREMENTS DIVISION.

As the placing of orders was always so far behind the requirements schedule that there appeared to be no possibility of ever attaining the desired quantities, it was comparatively simple to arrange that a few weeks prior to the expiration of a contract, a renewal order could be negotiated. Procurement requests could then be asked of the Estimates and Requirements Division when not already in hand, so as to insure continuous operation of all plants. In order to put through a requisition for a contract, it was necessary to wait for the physical possession of the procurement request because that contained numbers and data which were required (by the Contract Section) before any action could be taken. Classification, price basis, and various other items were called for on requisition, and 15 copies of each requisition were entered and distributed to interested divisions. The work (of the Contract Section) was so tremendous and the varieties of material on order by the Procurement Division so diffuse that it occasionally happened that an order was completed before the contractor received his printed contract. Letters of award were promptly dispatched as soon as negotiations had been concluded apprising the contractor that a requisition for a contract had been entered. This permitted him to make all needful preparations in advance of receiving the actual order and prevented many delays which would have occurred had this method of procedure not been adopted.

In order to safeguard the United States, checks were required of both the negotiator and the section head before the proof copy of the contract went to the printing office. This insured precise confirmation of various orders which the emergency demanded be given verbally, or semiofficially. When the final proof of contract had been signed by the negotiator and the section head, 30 copies were struck off and three copies signed by the contracting officer for the Government. If also approved by the contractor, the contract was then in force and a true copy was sent to the district office for its guidance and to constitute authority for the disbursing officer at that point to make payments thereunder.

ORDERS PLACED.

Orders to the sum of $929,586,804.18 were placed with various companies for explosives and miscellaneous products, for the construction and operation of by-product coke oven plants and for the construction of toluol plants.

Prior to the war the price of smokeless powder, as fixed by Congress, was $1 per pound. After stabilizing the manufacture of this explosive which in point of quantity was the largest on the Explosives program the price showed a gradual decline (with the exception of small lots for experimental purposes and such minute quantities of special blend as were required for proving ground purposes and ballistic tests), until the last renewal contracts which were made at the base price of 34¼ cents per pound. Reports furnished by the Cost Accounting Section indicated production at the Nashville plant at about 38 cents per pound.

A total of 61 contracts was made with 14 different companies for 809,444,630 pounds of smokeless powder, at prices ranging from 20 cents to $1 per pound.

Comparatively slight variations were met with in the purchase of black powder. The price was in the neighborhood of 25 cents per pound during the entire period of the war. While this is higher than the prewar price, it is easily accounted for by the fact that the principal component (saltpeter) had advanced about 500 per cent in cost. Twenty-nine contracts for amounts totaling 17,183,673 pounds were made with six large powder companies at 24½ to 32 cents per pound.

The sudden call for picric acid, for which there had been no demand prior to the war, found no facilities existing for production in quantity. In the second and third years of the war it sold as high as $3 and $4 per pound, but at the time of the signing of the armistice, due to the development of Government-owned plants and production from plants of private contractors, the acid was being produced at prices ranging from 53 to 56 cents per pound. It was confidently expected that as soon as the three Government-owned plants at Little Rock, Ark., Grand Rapids, Mich., and Brunswick, Ga., were in full operation the price of this product would be reduced to about 45 cents per pound. The first-mentioned plant was the only one that arrived at production, although insufficient material was produced to form any estimate as to the ultimate price of the acid produced in quantity. In all 18 contracts were made with 11 companies for 251,234,000 pounds.

The production of T. N. T., being dependent upon the supply of toluol, was at first only in small quantities, but necessarily at a high price. When the great need for the explosive developed it was, therefore, necessary as a part of the production to contract for the construction and operation of plants for the recovery of toluol with the various public utilities corporations, and also take measures to develop by-product coke ovens in order to increase the supply of benzol. The prewar price of T. N. T. was about 29 cents per pound. During the second and third years of the war toluol sold as high as $7 per gallon, but the majority of contracts were at the rate of $1.50 per gallon, and the price of T. N. T. ranged from 35 to 50 cents per pound. Renewal contracts, however, were made on a basis price of 26½ cents per pound, with every expectation that, as a result of cooperation between the contractor and the United States, this price could have been still further reduced had the war been prolonged. Twenty-seven contracts were made with 11 manufacturers for approximately 339,345,900 pounds at a price ranging from 35 to 67 cents per pound. In order to procure the toluol necessary to carry on the Explosives program, 54 contracts for the purchase at $1.50 per gallon, 7 for refining toluol at 7 to 10 cents per gallon, and 24 for the operation of toluol plants at 40 cents to $1.50 per gallon, totaling 19,288,275 gallons, were made.

The bulk of the 499,591,555 pounds of ammonium nitrate contracted for was produced in the usual commercial manner by nitrating ammonia and the production of nitric acid by the contractor from sodium nitrate and sulphuric acid. The majority of the 26 contracts made obligated the Government to supply sodium nitrate, sulphuric acid, and ammonia, but due to the shortage of the latter component very earnest efforts were being made to develop other methods of production, such as the Brunner-Mond ammonium sulphate sodium nitrate process, the fixation of atmospheric nitrogen by the cyanamid, and flaming electric arc methods. Negotiations were concluded with the British-American Nitrates Co. to design, build, and operate a plant at Glenlyn, Va., by the Kilburn-Scott flaming arc method of nitrogen fixation, but these plans did not mature owing to the failure of the contractor to obtain adequate financial backing. The Perryville plant, operated by the Atlas Powder Co., was about to enter on a period of maximum production at the time of the armistice. Prior to the war practically all ammonium nitrate used in this country was imported from Norway, where it is produced in a high state of purity by the fixation process, which can be accomplished very cheaply due to the prevalence of water power. Very little reduction in price was brought about as compared with prewar prices, and the amount being produced was at all times far behind the requirements schedule. Had the plants at Sheffield been fully developed and the Perryville plant operated at capacity for a time, it is probable the prices would have been reduced.

Prior to the war ammonium nitrate sold as low as $0.059 per pound, as compared with the cheapest price at which it was produced during the war (at Perryville) of 12 cents per pound. The prices paid private contractors averaged 15 cents per pound for several months before the armistice. The last contract price, for a renewal, which was made with the Atlas Powder Co. for their entire production for the first six months of 1919, was at $0.148 per pound, although as much as 22½ cents per pound was required for some orders.

Five of the six contracts entered into for the production of 4,136,000 pounds of tetryl were on a basis of 90 cents per pound. One contract with the Bethlehem Loading Co. was on the "cost-plus" basis.

The prices paid for tetranitroaniline were from $2 to $2.50 per pound from private contractors. The plant which was being developed for production in quantity by the Calco Chemical Co., was never completed and the method upon which the installation was founded was commercially impractical, with the construction running up to five times the estimated cost. No explosive had been produced under this contract at the time of suspension. However, 1,015,608¾ pounds had been contracted for with that company and the Aetna Explosives Co.

The manufacture of ammonium picrate, having as its base picric acid, was generally collateral with the production of picric acid itself and by the same contractors. The prices varied from 59 to 70 cents per pound, and the tendency in the later months of 1918 was toward lower prices, thus keeping pace with the reduction in the cost of picric acid. Thirteen contracts were made with five different companies for 18,150,000 pounds ordered.

Prices for fulminate of mercury varied from $3.17 per pound to $3.275 per pound. This substance naturally showed very much lower figures than any other explosive, totaling only 421,000 pounds. Owing to the comparatively narrow market for mercury, it was necessary in practically every instance for the United States to acquire the principal component for the purposes of the contractor. Orders were placed with the E. I. du Pont, Atlas Powder, and the California Cap companies.

Grenade powder was practically all produced by one contractor, Pennsylvania Trojan Powder Co. (who also produced the ammonium nitrate, which is a component of the grenade powder. Four contracts to the amount of 49,750,000 pounds were entered into, the prices varying from 21 to 25 cents per pound, depending on the quantity. One small lot was purchased from the E. I. du Pont de Nemours & Co. at 37 cents per pound, and several experimental lots of 50 pounds at as much as 50 cents per pound.

Contracts for other materials used in connection with the Explosives program and for the construction of necessary plants for toluol and benzol will be listed below, with the explosives discussed, giving total quantities and total values.

Report of contract totals.

DEC. 23, 1918.

Material.	Total quantities contracted for.	Total value.
Ammonium nitrate.......pounds..	499,591,555	$43,744,469.36
Ammonium picrate.......do....	18,250,020	11,646,708.50
Fulminate of mercury.......do....	421,000	1,345,073.17
Lyconite (E. L. 104).......do....	1,120,000	313,600.00
Picric acid.......do....	251,234,000	136,458,740.00
Black powder.......do....	17,183,675	3,543,478.53
Grenade powder.......do....	49,800,260	11,470,094.00
Smokeless powder.......do....	809,444,630	382,548,252.30
Pyro cotton.......do....	56,183,270	19,584,302.60
D. N. B.......do....	36,300	14,520.00
Tetryl.......do....	4,136,075	4,782,467.50
T. N. A.......do....	1,015,609	4,135,512.19
T. N. T.......do....	297,146,000	158,526,958.00
Cartridge cloth.......yards..	58,742,625	34,131,780.15
Powder bags.......sets..	14,458,509	3,256,798.10
Powder rings.......	61,110,387	1,257,864.26
Felt.......yards..	89,000	107,835.00
Spun-silk thread.......pounds..	382,047	2,150,038.00
Bag-loading plants.......rounds..	6,000,000	13,679,164.00
Primer protector caps.......	311,000	49,390.00
Loading cartridge cases.......	137,600	275,200.00
Shotgun shells.......	12,687,700	295,628.85
Powder boxes.......	1,121,832	773,244.30
Absorbent oil.......gallons..	2,035,900	235,988.00
Light and holder oil.......do....	316,676	44,819.79
Purchases of toluol.......do....	7,660,858	9,389,159.00
Refining of toluol.......do....	6,916,667	498,220.00
Operation of toluol plant.......do....	4,710,750	9,968,625.00
Construction and operation of toluol plants.......	....	7,262,175.86
By-product coke-oven plant.......ovens..	1,475	59,644,000.00
Construction of toluol plants.......	....	5,376,700.00
Experimental work, toluol.......	....	194,209.76
Increased plant facilities.......	....	440,393.50
Experimental work, miscellaneous.......	....	234,094.48
Purchase and lease of land.......	....	314,147.87
Miscellaneous powder component.......	....	142,647.63
Miscellaneous.......	....	1,786,364.48
		929,586,804.18

CHAPTER V.

PRODUCTION OF EXPLOSIVES.

The production of explosives includes not only the production of the raw materials, propellants, and high explosives, and propellant assembly, but also the loading of the finished material into shell.

RAW MATERIALS.

Of all the problems that confronted the Ordnance Department in connection with the manufacture of propellants and high explosives to meet the requirements of the military program that of providing an adequate supply of a great variety of the required raw materials was one of the most difficult to handle. The problem resolved itself into that of producing the following chemical substances: First, those used in common in the manufacture of propellants and high explosives, namely, alcohol, sulphuric acid, nitric acid, ammonia, caustic soda, sodium nitrate, and sulphur; second, those used in the manufacture of propellants, namely, cotton linters and diphenylamine; third, those used in the manufacture of high explosives, namely, toluol for T. N. T. and benzol and phenol for picric acid.

Although there was a great demand for alcohol for various industrial and war purposes, the Production Division was able to let contracts by which increased facilities were developed with private capital to keep pace with the Explosives program. Although the alcohol requirements were remarkably large, no difficulty was encountered in obtaining an adequate supply at all times.

At the beginning of the war there appeared to be little likelihood that the Ordnance Department would require phenol for explosives manufacture, as there was no intention of using picric acid as a shell filler. However, owing to the scarcity of munitions in the early part of the war, the department borrowed a large quantity of picric acid from the French Government and agreed to manufacture an equal quantity in the United States to fulfill this obligation. Raw materials were also being obtained in this country by the French for the manufacture of picric acid, which were exceedingly bulky, requiring a large amount of cargo space, which at the time was greatly needed for other military necessities. In order to conserve this space, it was decided that the finished product, picric acid, for French consumption which required much less shipping space than the raw materials, should be manufactured in this country. Accordingly several arge picric-acid plants were erected. Prior to the war phenol was produced only in small quantities in the United States from coal tar, but during the year 1915 the price bid by the Allied Governments stimulated the erection of several synthetic phenol plants. The output of the country being, however, inadequate to supply the requirements of the new picric-acid plants, it became necessary to arrange for the construction and operation of phenol plants capable of producing approximately 15,000,000 pounds per month. The actual production of approximately 10,000,000 pounds per month was attained at the time of the signing of the armistice.

The benzol capacity of the country had been so greatly increased as a result of the work of the Ordnance Department in increasing toluol production that there was always an ample supply for the phenol plants and no difficulty was encountered in letting contracts at a reasonable price.

Difficulty was encountered, however, in obtaining an adequate supply of caustic soda until the entire production of the country was commandeered. After taking that step the work consisted principally in obtaining clearance for manufacture and in allocating the required quantities to the explosive plants. This material was used extensively in the manufacture of phenol.

Shortly after the beginning of the war it became apparent that there would be a considerable shortage of sulphuric acid, the very important basic material for explosives and propellant plants. A survey of the situation was therefore made and as a result arrangements were made with the Tennessee Copper Co. and the Anaconda Copper Co. for the erection of plants at their own expense for the manufacture of sulphuric acid from sulphur dioxide recovered from the waste gases of smelting operations. The completion and operation of these plants materially relieved the shortage. In addition to these sulphuric acid plants were erected by the Ordnance Department in connection with every new high explosives and propellant plant and arrangements were also made to furnish sulphur to these plants. In this connection, the large sulphur deposits of Louisiana and Texas were extensively developed.

The great importance of nitric acid in the manufacture of explosive materials made it necessary to watch its production closely at all times. The nitric acid during the emergency was such that until August, 1918, explosives requirements were all taken care of by either direct construction of the Government or by construction made at the direction of the Government. About August 1, 1918, due to new requirements, a survey of all nitric acid plants was made which resulted in the disclosure that all plants were operated at maximum capacity and further requirements would require construction for increased facilities. The ability of the Aetna Explosives Co., General Chemical Co., and the Western Chemical Manufacturing Co. to supply small lots at this time aided in tiding over the situation. New contracts for increased facilities were under construction and about decided upon when activities ceased November 11.

During the early part of the war there was an adequate supply of diphenylamine, but during the summer of 1918 the Chemical Warfare Service made requisition on the Ordnance Department which was charged with the purchase of this material for use as a stabilizer in smokeless powder, for an amount about fifty times the annual powder requirements of the entire country. In order to meet this requisition, an investigation was made relative to the construction of a large new diphenylamine plant. The signing of the armistice, however, caused the suspension of these negotiations.

The tremendous consumption of nitrate of soda for the manufacture of nitric acid and ammonium nitrate made it necessary to import very large quantities of this material from Chile, and to keep a reserve stock of approximately 800,000 tons on hand to provide for a possible period when shipping operations might be interfered with by submarine activities. The work of furnishing nitrate of soda consisted principally in arranging for a receipt of nitrate vessels from Chile for the acceptance and storage of their cargoes and for allocating supplies to the nitric acid plants. There was no shortage of this material.

Ammonia was produced in three forms: Powder quality liquor, averaging about 22 per cent ammonia; aqua ammonia, averaging about 28 per cent ammonia; and ammonium sulphate. The powder quality liquor and the aqua ammonia were used principally at ammonium nitrate plants using the neutralization process. Ammonium sulphate was consumed principally by the United States ammonium nitrate plant at Perryville, Md., although during the period of ammonia shortage a considerable quantity was distilled at one neutralization plant. There was at all times a considerable shortage of ammonia. This was regarded as one of the reasons for recommending the coke-oven program which is described later.

The extensive use of cotton linters in the manufacture of smokeless powder made it necessary to provide for a maximum production of this material. At the beginning of the war cottonseed-oil mills were recovering about 60 pounds of high-grade lint from each ton of seed crushed and this material was being used principally for padding mattresses. About an equal amount of lint was left on the seed, as its fiber was so short that it was unsuitable for padding purposes. The necessity for removing all of the lint from the seed was impressed upon the cottonseed-oil mills. Many conferences were held with lint producers and the cooperation of the War Industries

Board was enlisted with the result that a price of $0.0467 per pound was fixed for munitions grade lint. A standard of 145 pounds per ton of seed was set as a minimum performance and mills were warned that failure to recover this quantity would serve as a basis for recommendations to the War Industries Board to shut down their plants and to divert their seed to more efficient mills. The Du Pont American Industries Co. was employed as a purchasing and inspecting medium as this company already had an extensive force which was visiting more than 600 lint producers whose mills were scattered throughout the South. At the same time a staff of technical experts was organized and small inefficient mills were assisted in maintaining their production at a maximum. However, in spite of this work it became evident that there would be a shortage of lint after the large smokeless powder plants were put into operation, and experiments were undertaken to develop a substitute. Bleached rags were used successfully, and a contract was let for several million pounds of this substitute. However, the contractor had difficulty in obtaining raw material and practically no deliveries were made on this contract. The most promising substitute, and one which had been adopted on a commercial scale, was wood pulp.

The production of toluol, which is the basic raw material for the manufacture of T. N. T., was increased to meet requirements. Toluol was produced at the beginning of the war as a by-product existing in the gas produced by coke ovens and city gas plants. Prior to 1914 a few coke-oven plants recovered it, but the majority as well as the city gas plants permitted it to remain in the gas. After the beginning of the war, in 1918, the Allied Governments quickly developed all of the toluol resources and were forced to resort to the United States to make up their deficiencies. As a result the price of toluol, which had been stagnant at about 24 cents per gallon, increased by leaps and bounds until such prices as $10 and $12 per gallon were paid. These high prices stimulated coke oven operators to erect toluol plants so that the entry of the United States into the war found this country producing about 750,000 gallons of toluol per month. It soon became evident, however, that the production of the country had to be considerably increased, and on October 2, 1917, a program was presented calling for erection of toluol apparatus in the gas plants of 32 large cities of the country. The construction cost of these plants was estimated at $7,000,000, and their output of toluol at 4,000,000 gallons per year. This program was approved and arrangements made for the construction of the plants and for their operation by the gas companies. On account of the delays incident to the severe winter and to the orders of the Fuel Administration, the first plant was not completed until April, 1918, the others being put into operation within the six months following. It was soon realized that further steps must be taken to increase the toluol production, and accordingly an exhaustive investigation of every source which showed promise was begun. Recommendation was made that the Ordnance Department encourage the erection of new coke-oven plants by making contracts for their output of ammonia and toluol, and in February, 1918, the Procurement Division was instructed to make contracts for the output of about 1,500 ovens. The construction of these plants was begun promptly, and four of the contracts provided for the erection of plants at the expense of the Government.

Another investigation which was successfully carried out was the production of toluol from solvent naphtha. One plant was successfully operated for over six months and the second was ready to begin when the armistice was signed.

However, the achievement which opened the largest source of toluol and one which assured the Ordnance Department of almost unlimited supply was the development of the oil cracking process. Investigation of this process was begun by the Ordnance Department in November, 1917, and a corps of chemists and engineers was sent to Los Angeles in February, 1918. The work was actively carried on for over five months, although the results obtained in the first month of the experimentation were encouraging enough to warrant a recommendation for the erection of a plant for producing toluol by this process. The estimated cost of the plant was $2,000,000 and its estimated production 2,000,000 gallons of pure toluol per year. This plant was put into successful operation and all of the units would have been in operation in January, 1919. The part of the plant which operated proved that the capacity would have been at least 3,000,000 gallons per year. In July, 1918, the construction of the two plants of 3,000,000 gallons capacity was begun at San Francisco. Considerable construction work had been done on these plants at the time of the signing of the armistice, but no production of toluol was obtained from them. In connection with the experimental work and in order to be prepared to further increase the production of toluol, investigation was made of the oils produced in all of the large fields west of the Mississippi River, none of which proved suitable for toluol production by this cracking process.

Toluol production increased from 850,000 gallons per month in September, 1917, when the work was undertaken, to 1,700,000 gallons per month in October, 1918. The completion of the plants under way would have increased the output to about 2,500,000 gallons per month, and it would have been possible to recommend the erection of oil cracking plants to produce toluol economically and in quantity up to 5,000,000 gallons per month.

The transportation situation which arose in connection with the manufacture of large quantities of benzol, phenol, and sulphuric acid demanded a much larger number of special type tank cars than was then available. To meet this situation the construction of 1,200 such cars, at an approximate cost of $3,500 each, was authorized.

PROPELLANTS.

The production of propellants begins with the receipt of raw material and ends with the delivery of the finished powder at the loading plant, or, as has been the case during this war, at seaboard for overseas shipment. There are two main classifications for propellants—black powder and smokeless powder, each of which calls for a container. The manufacture of smokeless powder divides itself into the production of pyro cotton or guncotton and the converting of guncotton into smokeless powder.

BLACK POWDER.

The production of black powder was at all times in excess of requirements. Plant capacities in the United States and Canada were not increased, excepting that commercial plants were slightly altered to produce Army grades more economically. No change in the process of manufacture was made. While the various contractors or manufacturers used somewhat different processes, the following brief description applies in general:

Charcoal and sulphur are pulverized at the same time in a ball mill, which consists of a revolving steel cylinder in which iron or steel balls do the crushing. This pulverized material is mixed either with pulverized saltpeter or stirred into a saturated solution of saltpeter. The resultant mass is then spread over a flat surface or bed and subjected to a further mixing or incorporating by being rolled or ground under steel wheels, weighing 8 tons each. It is estimated that each particle of the mixture is subjected from 1,500 to 1,800 movements and crushings. The mixture is then pressed into slabs or cakes, approximately 24 inches square and three-fourths inch thick, under uniform pressure, so that when the powder is crushed it is broken into grains instead of crumbling. The cakes are crushed by passing them through granulating or crushing rolls. The grains are rubbed, dried, and polished, usually in one operation, the smoothing and polishing being accomplished by the rubbing and tumbling of the grains in a revolving cylinder. Hot air is forced through the cylinder during the rubbing process to carry away excess moisture. A small quantity of graphite is added to the powder shortly before the tumbling operation is completed. This graphite coats the surface and gives the powder a bright polish and prevents to some extent the absorption of moisture by the powder. The various sizes or grades are obtained by screen sizing, after which the powder is packed in steel drums or cans, containing 25 pounds each. Each can is stenciled to record necessary Ordnance information. Previous to August, 1918, containers were not reused. After that time arrangements were made for the reuse of containers effecting a saving of $5,000 per month.

SMOKELESS POWDER.

Smokeless powder is made from pyro cotton, which is sometimes called guncotton, by treating this material with a sufficient quantity of ether alcohol mixture to destroy the fibrous cotton structure, and produce a plastic mass which will permit the formation of grains or granules, the sizes of which depend upon the caliber of the gun for which it is required. It follows that the manufacture of pyro cotton is an extremely important part of the manufacture of smokeless powder. This manufacturing process may be outlined in successive steps as follows: The cotton linters and hull shavings, which are the short fiber cotton left on the seed after the staple cotton has been ginned, is first purified in caustic soda solution, thoroughly washed in water, then bleached and shredded and dried. The cotton fluff is then immersed in a mixture of nitric and sulphuric acid, known as mixed acid. The nitric acid acts on the fiber, producing nitro-cotton or pyro cotton, the sulphuric acid absorbing the water, which is a by-product of this reaction. The surplus acid is wrung out of the cotton in centrifugal wringers and the cotton is drowned in water. Now begins a series of washings, boilings, and grindings in order to reduce the cotton to its finest possible state and cleanse it of any trace of acid and other impurities. The boiling is done in huge tanks or vats according to fixed schedule. After each boiling for a specified time the wash water is drawn off and fresh water is added. The grinding or pulping is done in beating engines similar to those used in the manufacture of paper. The entire process is subjected to control tests and at each stage of the process the various vats or sublots being mixed to give the pyro cotton a specified nitrogen content. After the wash is complete the surplus water is wrung from the cotton by means of centrifugal wringers similar to those used in laundries. It is then fed into presses which remove a further amount of water, after which a definite quantity of alcohol is added to the mass of cotton pulp. This alcohol displaces the water left in the mass; and the percentage of water left in the pyro cotton is reduced to a very small fixed percentage. When dry it is extremely sensitive and is classed as a high explosive.

For the manufacture of smokeless powder the pyro cotton is dehydrated with alcohol and treated with ether which converts the pyro cotton into a plastic mass. This mass passes in turn through blocking presses, and the final or finishing press which shapes the grain. The powder comes from the finishing presses in threads when small-arms powder is being made or in various sized strings depending upon the caliber of the piece for which it is intended, the larger sizes resembling ropes. These strings or ropes are cut into lengths as required, varying from the thickness of paper to 1 inch or more in length for the larger calibers. The powder grains are then placed in closed bins, through which warm air is circulated to evaporate the ether and alcohol. The ether and alcohol are extracted from the circulating air and recovered for use. After the drying process reaches a point where it is no longer practical to extract the ether alcohol from the circulating air, the powder may be placed in dry houses for slow air drying or may be placed in large tubs of water for water drying, the water absorbing the ether and alcohol until in the later case the ether alcohol residue reaches a specified percentage. The powder from the water dryers is air treated to remove the external moisture. The dried powder is then packed in lots of from 60,000 to 125,000 pounds each, each lot being thoroughly mixed or blended mechanically. The powder is packed in zinc-lined boxes containing 150 pounds each, and shipped to a loading plant or an ordnance depot for storage.

In order to prevent changes from taking place in the powder, the boxes in which it is packed must be air-tight and must be so constructed that they shall remain air-tight. The re-use of boxes became a very important factor early in 1918. For the purpose of inspecting and repairing damaged boxes the United States box repair plant was established at Wilmington, Del. After the establishment of this plant all empty containers from box plants, loading and other plants were returned to this plant, where they were inspected, repaired, or destroyed, depending on their condition, the good boxes being reshipped to the powder plants. A total of 1,450,000 boxes were made before January, 1918, and 400,000 were repaired at the box-repairing plant during its operation. The only change in smokeless-powder containers made during the war was to increase the amount packed into each box from 140 to 150 pounds. Experiments carried on by the Department of Agriculture Forest Products Laboratory showed that changes were highly desirable for economic reasons. These changes reduced not only the first cost of the box but reduced the shipping space required, which was an extremely important item in connection with overseas shipment and the shipping of empty boxes.

Prior to 1914 there were five fully equipped smokeless-powder manufacturing plants in the United States with a capacity of 1,250,000 pounds of smokeless powder per month. At the time of the entrance of the United States into the war the capacity had been increased to 5,000,000 pounds per month. In November, 1918, the capacity had been increased to 53,000,000 pounds per month and new projects for construction would have within a very short time brought this total capacity up to 91,000,000 pounds per month. This increase was brought about in part by the establishment of separate plants for the manufacture of guncotton and smokeless powder.

At the time of the signing of the armistice four plants operated exclusively on the manufacture of pyro cotton. Four plants operated exclusively on the conversion of pyro cotton to smokeless powder. Eight plants were entirely or in part manufacturing the pyro they required in the manufacture of the smokeless powder—four of these latter plants are Government owned.

The Old Hickory powder plant at Nashville, Tenn., is a Government-owned plant and is deserving of particular mention. This plant was built and put into operation during 1918. It is the most complete and self-contained, as well as the largest of its kind, in the world. It includes plants for the manufacture of the acids required, recovery plants for acids, caustic soda, etc., purifying plants for guncotton, water supply and filtration plants, plants for the manufacture of ether, manufacture of diphenylamine, rectification of alcohol, waste disposal, laboratories, box factories, hospitals, commissaries, schools, churches, and a city for the housing of the more than 20,000 employees. The plant site is approximately 8 miles from the line of the Nashville, Chattanooga & St. Louis Railway, so that it was necessary to build 8 miles of standard-gauge track, including bridges, to connect the plant with the lines of the United States Railway Administration. This is in addition to the trackage within the plant, which has the capacity of placing 1,500 cars at one time and approximately 30 miles of industrial or narrow-gauge track. The plant is divided into nine complete powder manufacturing lines of 100,000 pounds daily capacity. The contract for the construction of this plant was signed in January, 1918, it being specified and expected that the manufacture of powder would begin on or about August 15. In spite of engineering obstacles and changes in plans which caused delay, the actual manufacture on the first line was started July 1 and the first acceptance was dated three months later. While an adequate description is not possible in an article of this kind, some idea of the magnitude of the undertaking may be obtained from the following: The powder plant contains 68 boilers of 825 boiler horsepower each, with stokers and electrical generating equipment of 17,500 kilowatts capacity. Water supply, 82,000,000 gallons per day; capacity of refrigerating plant, 3,250 tons of ice per day; acreage of plant site, 5,540. At the time of the signing of the armistice production had exceeded contract requirements by 85 per cent. With the signing of the armistice construction work ceased, the plant being 93 per cent completed, at a cost to the Government of about $88,000,000. The contract under which this plant was built was on the cost-plus-fixed-profit basis; the contractor was one of the large powder manufacturing concerns of the United States, who specified as a fixed profit the nominal sum of one dollar. This plant will be used as a Government arsenal; such buildings as are suitable because of their location and construction are being used as magazines for storing a part of the surplus smokeless powder now on hand in the United States.

The total investment in plants engaged in the manufacture of propellants on November 11, 1918, is estimated at $362,000,000; the number of persons employed in the actual manufacturing process, 48,500.

While the process described above applies to practically all powder that was produced, there are exceptions in certain kinds of trench mortar and pistol powder, which use varying percentages of nitroglycerin.

Attached are photographs of interior views of the smokeless-powder plant at Picatinny Arsenal and two photographs showing powder grains of various calibers.

HIGH EXPLOSIVES.

The materials known as high explosives and which constituted the principal components of bursting charges for shell fillers, grenades, and bombs of various kinds and used by the United States Army in the present war, included the following: Trinitrotoluol, ammoniuim nitrate, picric acid, ammonium picrate, lyconite, tetryl, fulminate of mercury, tetranitroaniline, nitrostarch powder, and ammonium chloride.

PRODUCTION PRIOR TO AUGUST, 1914.

Previous to this date the production of high explosives for military purposes was very limited. Ammonium picrate was used for the standard bursting charge of armor-piercing shell and T. N. T. had been adopted in 1912 as a bursting charge for mobile artillery, but neither of these substances were made in large quantities.

Picatinny Arsenal was the only place in this country where T. N. T. was manufactured for military purposes prior to August, 1914, and its manufacture was mostly for experimental purposes, the greater portion of the Army requirements being purchased abroad. There was some low-grade T. N. T. manufactured in this country for use in low-freezing dynamite. The ammonium picrate used for seacoast artillery and armor-piercing projectiles was manufactured at Picatinny Arsenal for both the Army and Navy.

Fulminate of mercury was the only detonator used at this time and the small amount required by the Government was supplied by private manufacturers.

Ammonium nitrate was not used by the Army at this time, but a large quantity was manufactured by the neutralization process to supply the demands of dynamite producers.

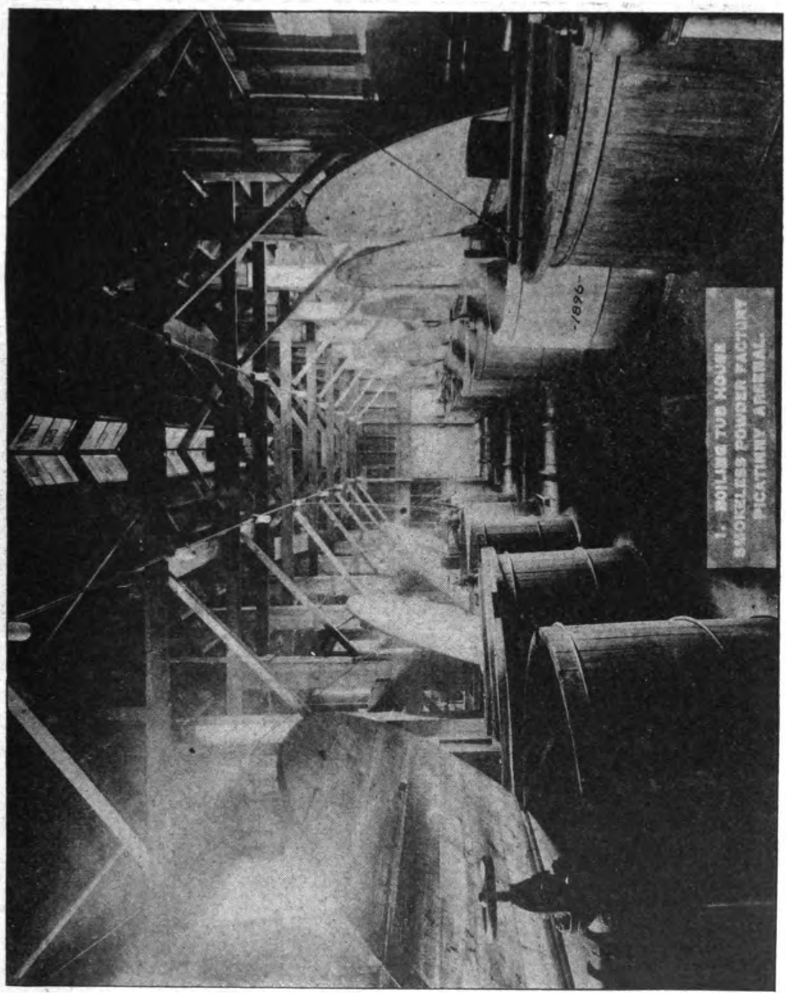
PRODUCTION FROM AUGUST, 1914, TO APRIL, 1917.

During this period the number of privately owned plants manufacturing high explosives for military purposes was greatly increased so that when the United States entered the war there were:

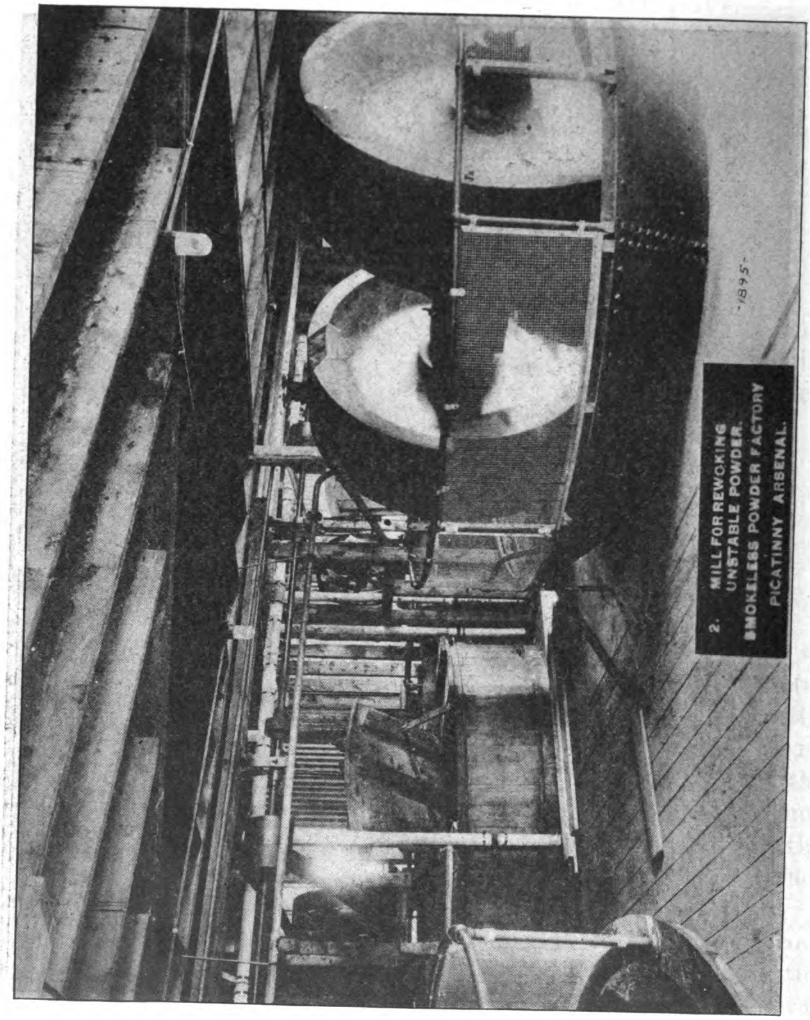
	Plants.
T. N. T.	5
Ammonium nitrate	1
Picric acid	6
Ammonium picrate	2
Tetryl	2
Mercury fulminate	4

These plants were all operating on foreign contracts. Some of this product was loaded into shell in this country, but the greater part of it was shipped to be loaded abroad. Improvements in the method of manufacture were being made during this period, but no attempt to standardize the methods of manufacture or layout of the plant from a safety standpoint had been made. The supply of some of the raw materials was limited and all had to be bought in the open market, which tended to make the prices of the finished product high.

The plants manufacturing T. N. T. were small and different processes were used. Some of the plants used what is known as the "one-stage" method. In this process the toluol, a coal-tar derivative, is agitated with a mixed acid and sulphuric acid of such strength that sufficient nitric acid is present to nitrate the toluol directly to trinitrotoluol. During this procedure the temperature must be under careful control. The product is then washed free of acid and dried. The result is crude T. N. T., very little of which was used. To produce refined T. N. T. this product is washed with toluol or alcohol. This process had some advantages from a safety

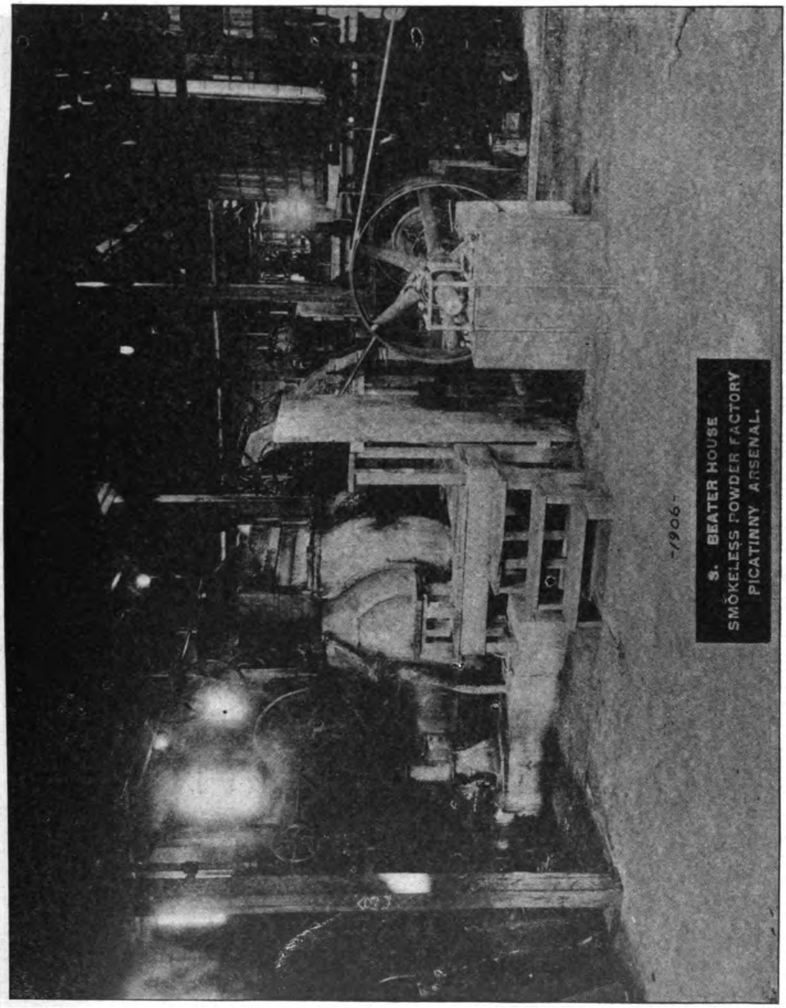

1896
1. BOILING TUB HOUSE
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.

62—1

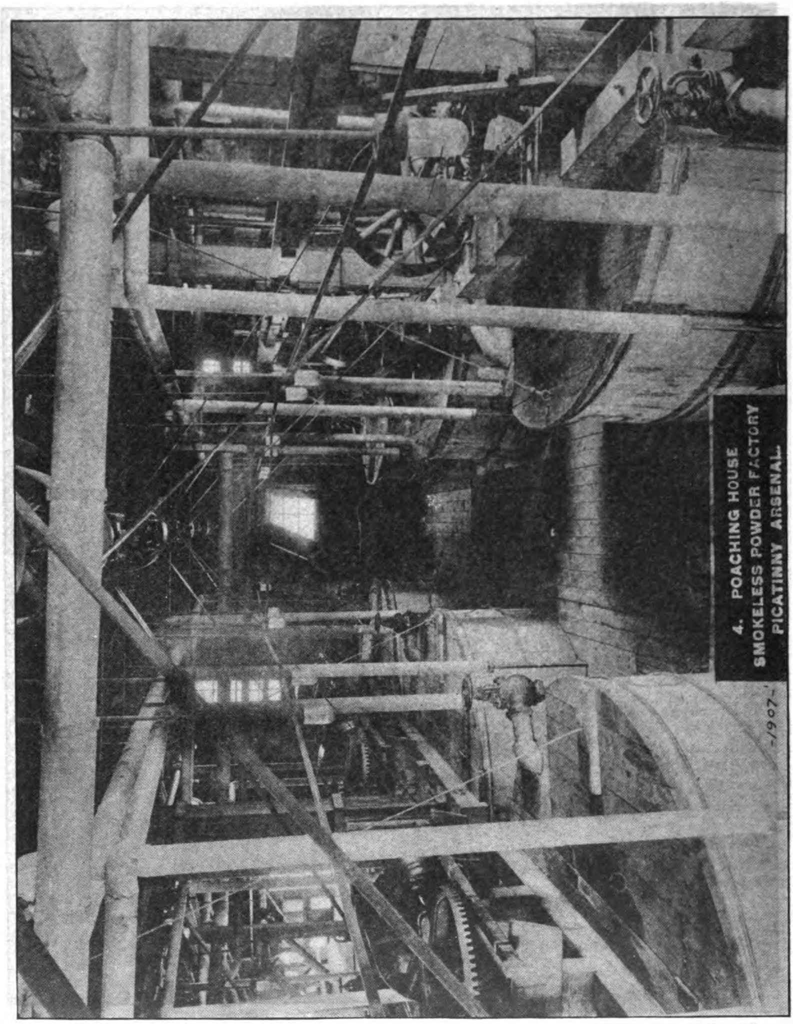


2. MILL FOR REWORKING UNSTABLE POWDER. SMOKELESS POWDER FACTORY PICATINNY ARSENAL.

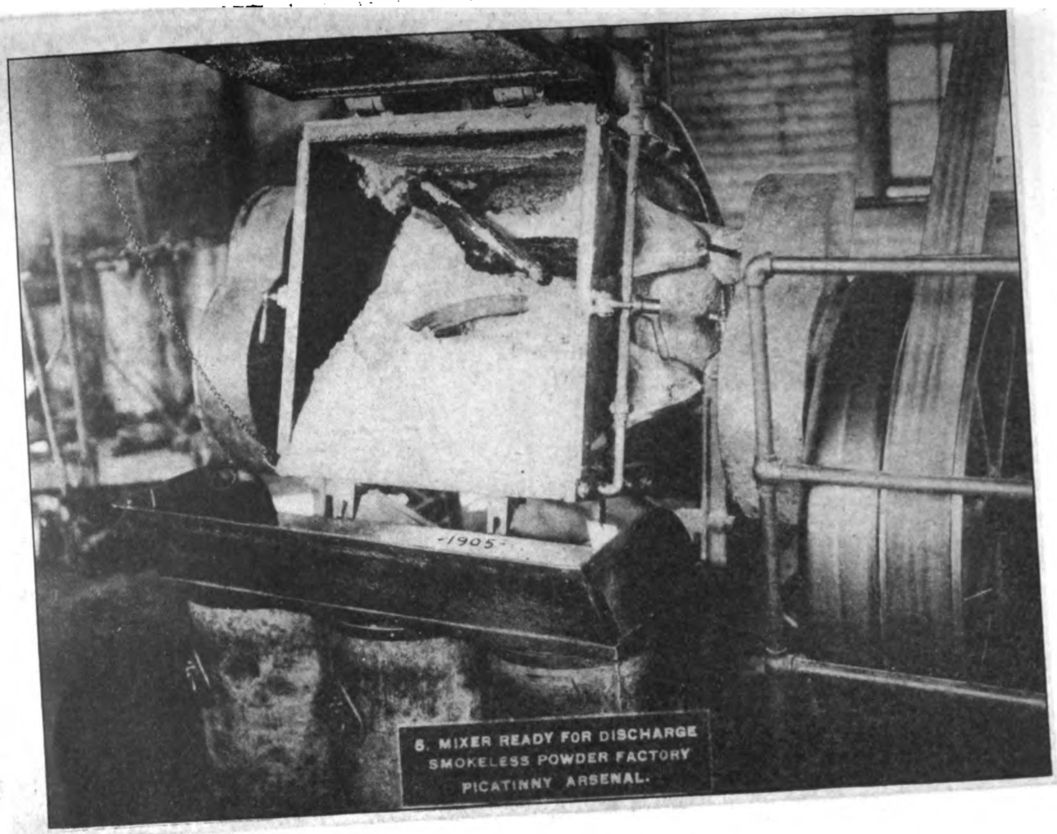
62—2



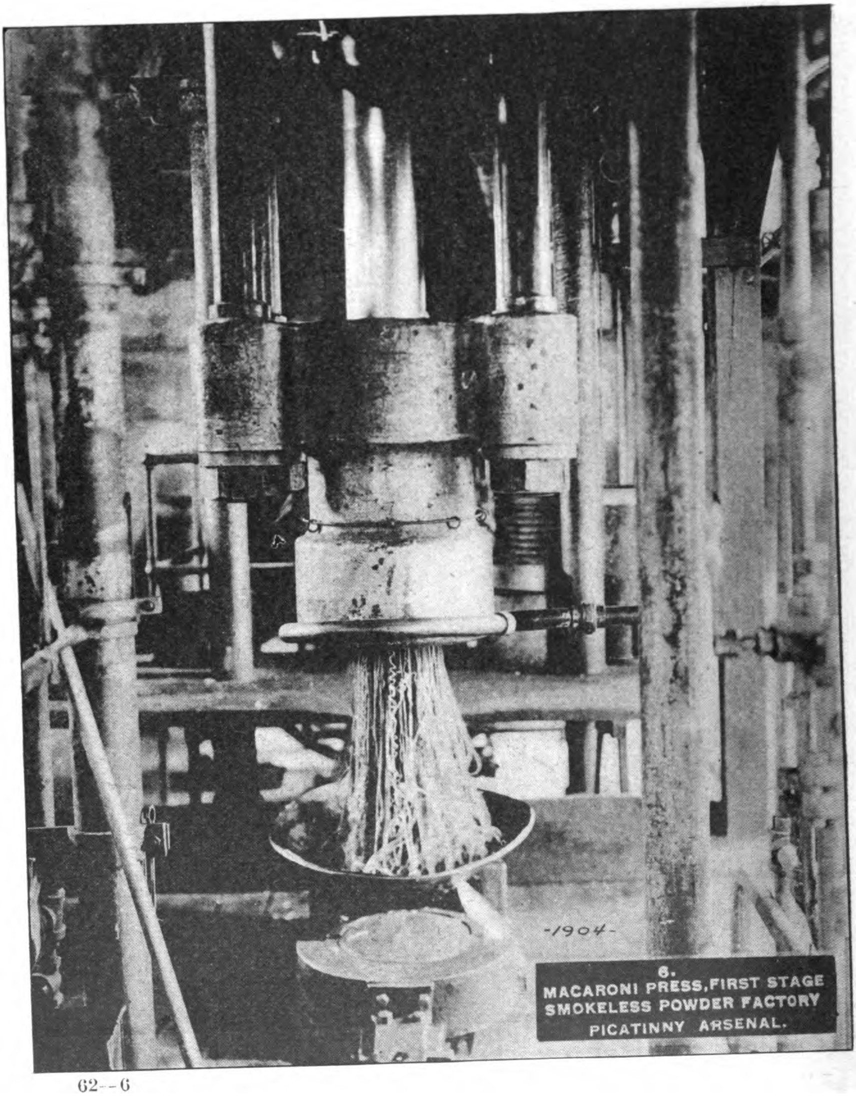
3. BEATER HOUSE
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.



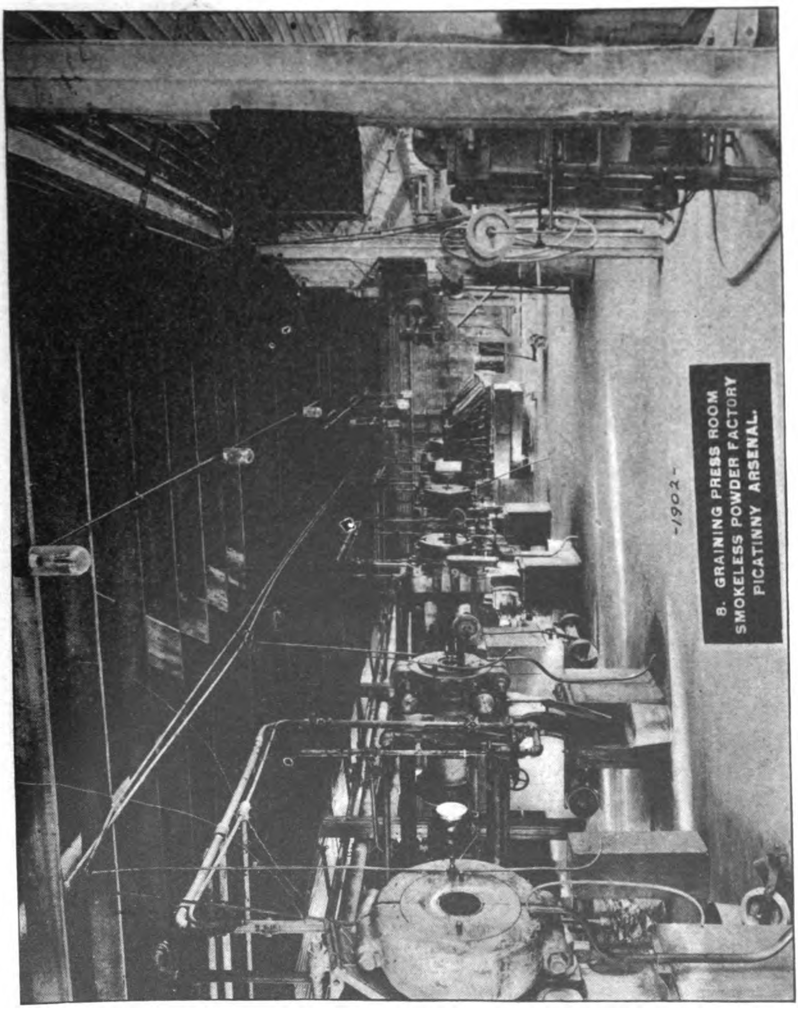
4. POACHING HOUSE
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.



6. MIXER READY FOR DISCHARGE
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.

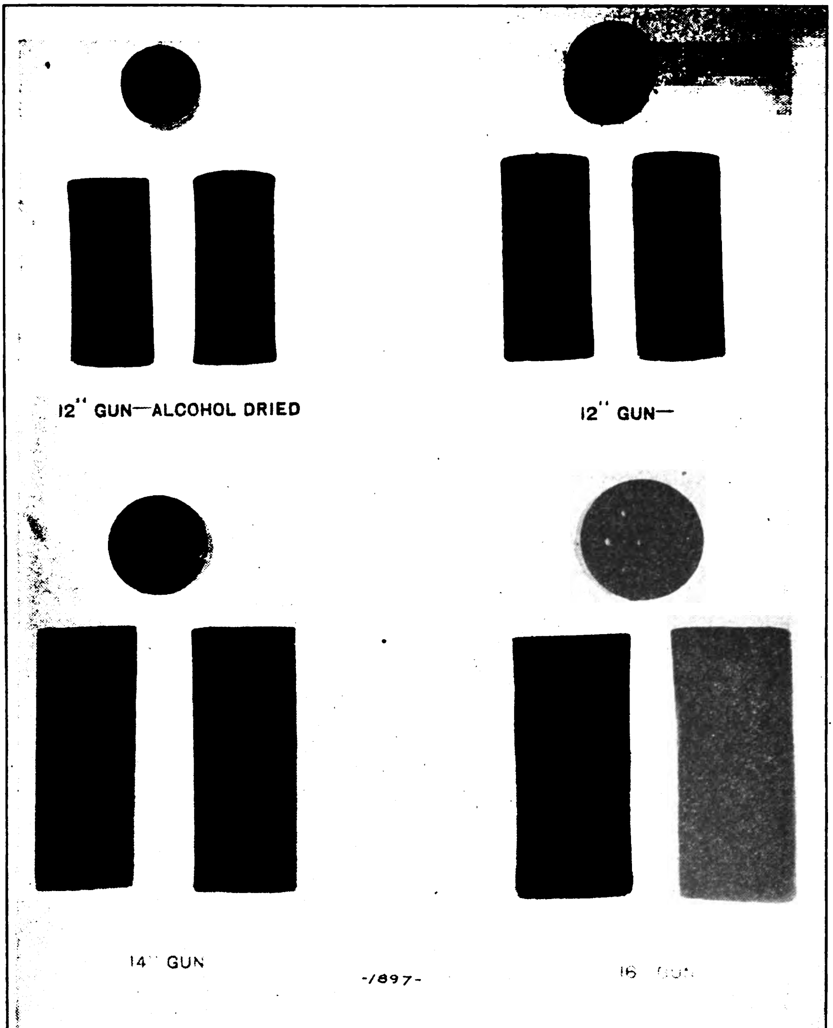

-1904-
6.
MACARONI PRESS, FIRST STAGE
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.

62--6

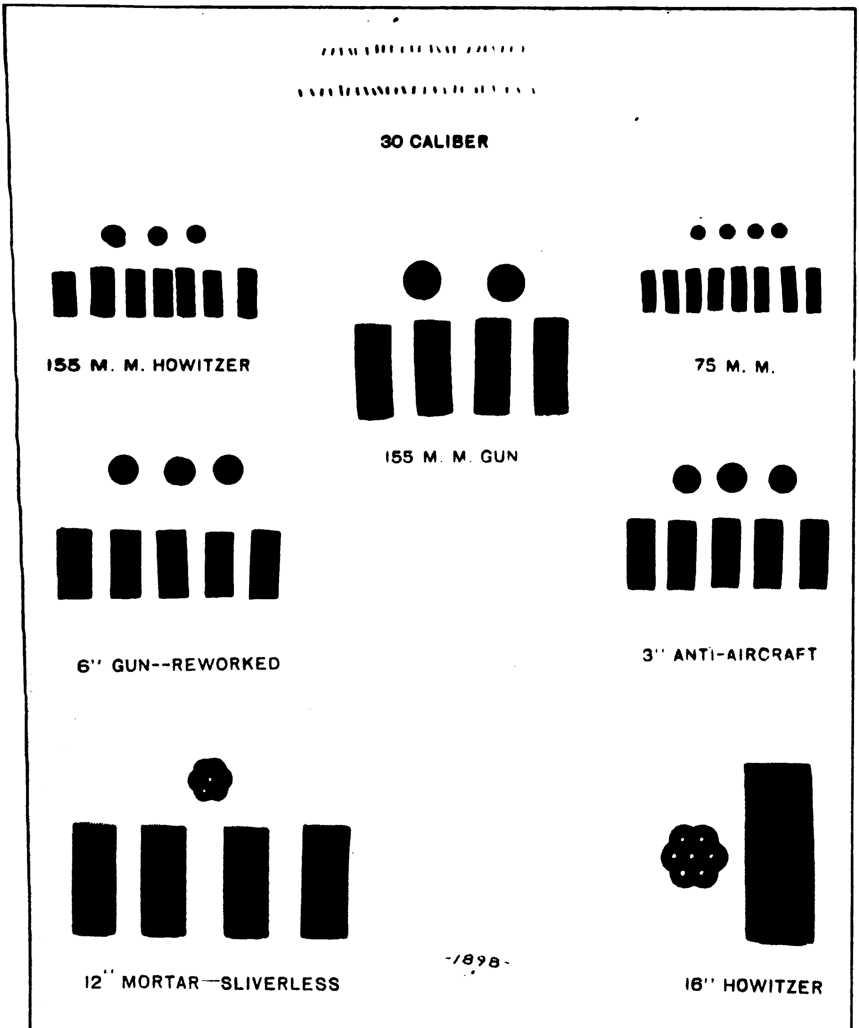


8. GRAINING PRESS ROOM
SMOKELESS POWDER FACTORY
PICATINNY ARSENAL.

62—7



SMOKELESS POWDER MANUFACTURED AT PICATINNY ARSENAL
PHOTOGRAPHED ACTUAL SIZE



SMOKELESS POWDER MANUFACTURED AT PICATINNY ARSENAL
PHOTOGRAPHED ACTUAL SIZE

standpoint but the consumption of raw materials was high. In the "three-stage" process the nitration is accomplished in three distinct steps with different strengths of mixed sulphuric and nitric acid. The waste acid is drawn off after each nitration. The price obtained for T. N. T. during this period on foreign contract went as high as $1.27 per pound at manufacturers' plants.

After the adoption of amatol by the British Government early in 1916, contracts were let by that country with private manufacturers in the United States for the production of ammonium nitrate to meet British requirements. This stimulated the production of this material, and by April, 1917, one manufacturer was producing a large quantity of ammonium nitrate on foreign contract. The neutralization process only was used. The grade made corresponded to what is now known as No. 1.

The companies making picric acid were all manufacturing for the French Government. This explosive was never adopted by the United States Government. The method used was first to sulphonate phenol, then to nitrate the phenol sulphonic acid to picric acid. The crystals of picric acid produced were washed with water and 10 per cent moisture was left in, in order that the material might be transported.

To make ammonium picrate, a 20 per cent solution of picric acid was put into large wooden tanks and concentrated ammonia passed in through the bottom; yellow crystals of ammonium picrate separates out and are centrifuged and placed in a dry house.

A limited quantity of tetryl was manufactured during this period and was used as a booster charge and in detonating caps. It was made from nitric acid, sulphuric acid, aniline, alcohol, and iodine. Some companies preferred to buy dimethylaniline instead of making it by heating aniline, alcohol, and iodine in an autoclave. The dimethylaniline is next sulphonated to dimethylaniline sulphate, which is nitrated by adding a mixed sulphuric and nitric acid, the result being trinitrophenylmethylnitramine, commonly called tetryl. It is one of the strongest explosives manufactured.

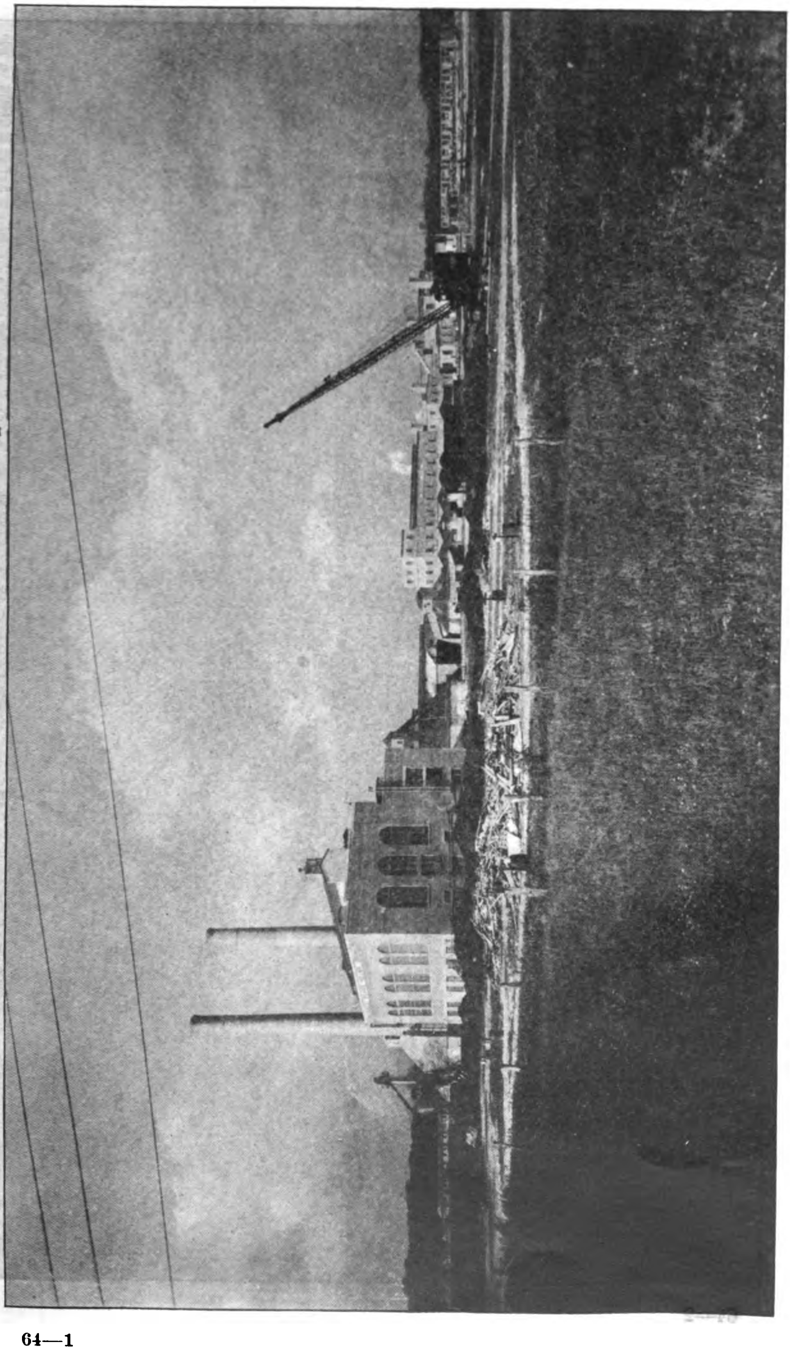
The plants manufacturing fulminate of mercury, which was used in detonators, had formerly been manufacturing it for the commercial trade, where it is used in blasting caps. The manufacture is carried out in two principal operations: First, the nitration of mercury to mercuric nitrate; second, the formation of mercury fulminate acid by the addition of ethyl alcohol. The amount of this explosive made at a time is very small, for the operation is very dangerous. Both operations are carried on in glass containers resting in a trough of water. The fulminate crystals that settle out are removed and washed on a cloth filter, placed in bags and sent to storage. The finished product is white to brownish gray.

PRODUCTION FROM APRIL, 1917, TO NOVEMBER, 1918.

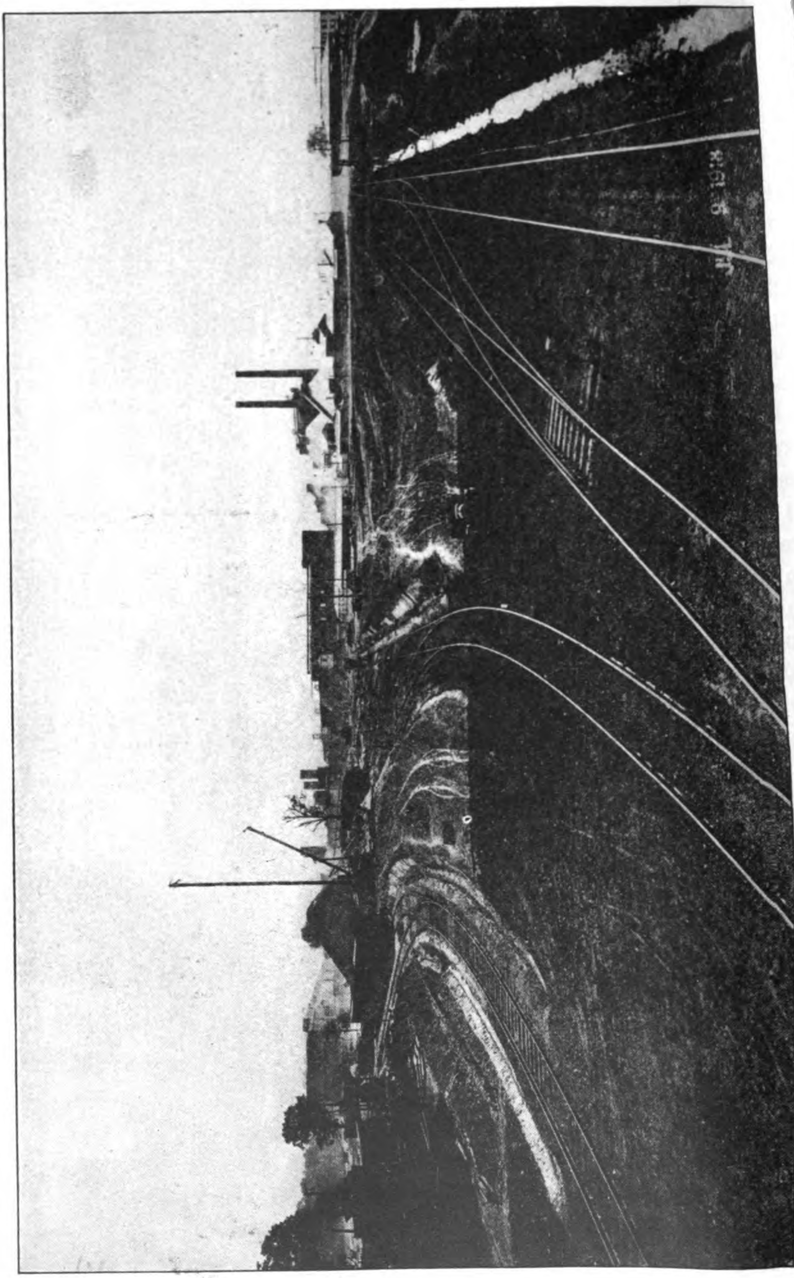
When the United States entered the war in April, 1917, a careful study of the military high-explosives situation was made by the Design Section of the Gun Division, which showed that the existing plants could produce but a small percentage of the explosives required to fill the program made out by the General Staff. At this time refined T. N. T. was the accepted shell filler for mobile artillery and ammonium picrate for seacoast artillery and armor-piercing projectiles. A careful study showed that not enough T. N. T. could be produced even by increasing the existing facilities and building new plants, for the supply of the important raw material—toluol—was limited. It was decided that the development of some explosives substitutes was necessary. Various explosives were considered, but there seemed to be two principal lines of development: First, to follow the French types of explosives of picric-acid mixtures; second, to follow the British system of amatol, a combination of T. N. T. and ammonium nitrate. To develop along the British line seemed more feasible, as it was a cheaper and safer explosive and more easily made in quantity. A cable was sent to the British ministry in September, 1917, requesting that a mission be sent to this country for the purpose of assisting us in the development of a high explosive. The mission on arriving produced such good evidence as to the logic of following the British policy that amatol was adopted by the Ordnance Department.

After amatol had been decided upon as a shell filler the capacities of many of the privately owned ammonium nitrate plants that had been producing for commercial purposes were enlarged. Several of the existing T. N. T. plants were enlarged and some new ones built, the Government financing some of these increased facilities. During 1918 as the requirements increased, due to increase in the size of the Army and different methods of warfare, it was decided to build Government-owned plants to manufacture T. N. T. and ammonium nitrate. The greatest difficulty encountered in providing increased production was the shortage of raw material and later the shortage of labor. The Government commandeered all the toluol in the country and spent large sums in increasing the toluol capacity.

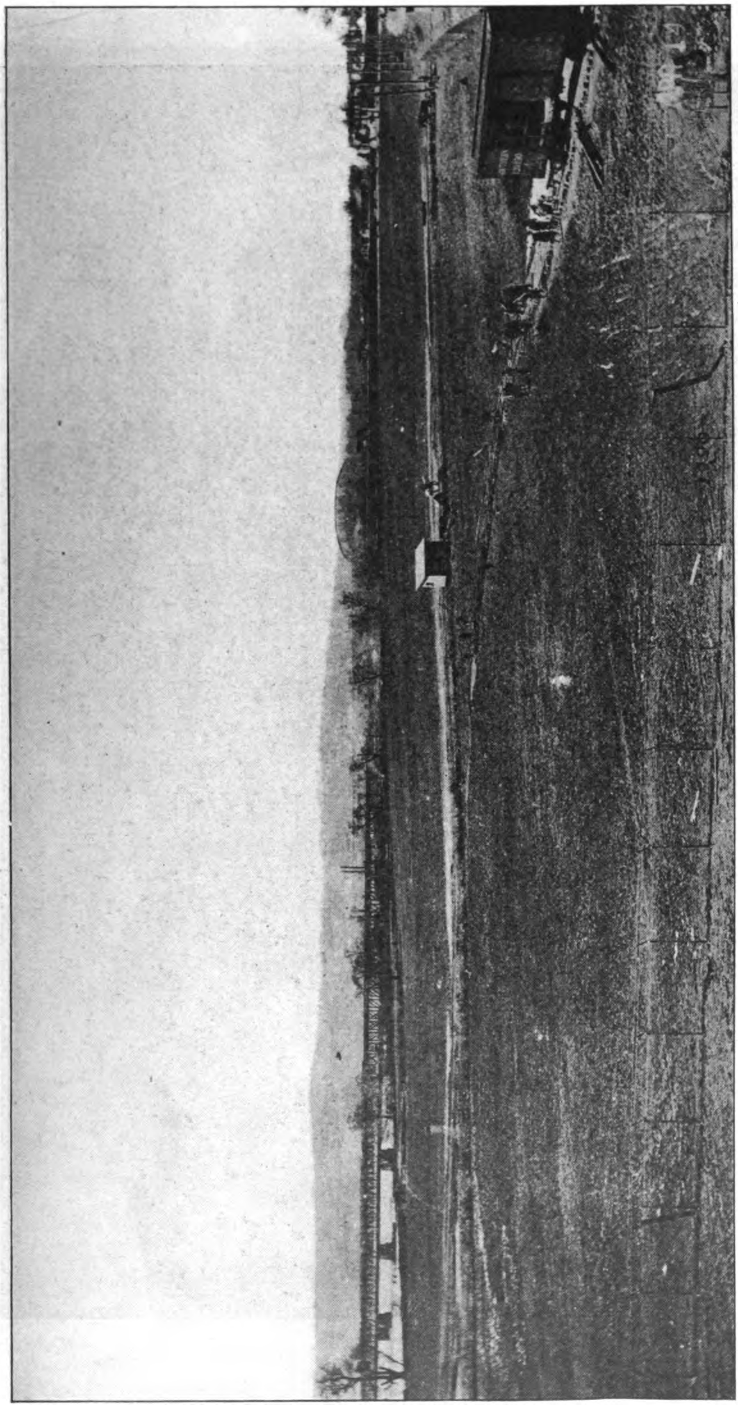
To supply the additional T. N. T. called for by the amatol program it was decided in the summer of 1918 to build three Government-owned T. N. T. plants. The following table shows the location, capacity in pounds per month, the total estimated cost, and the per cent

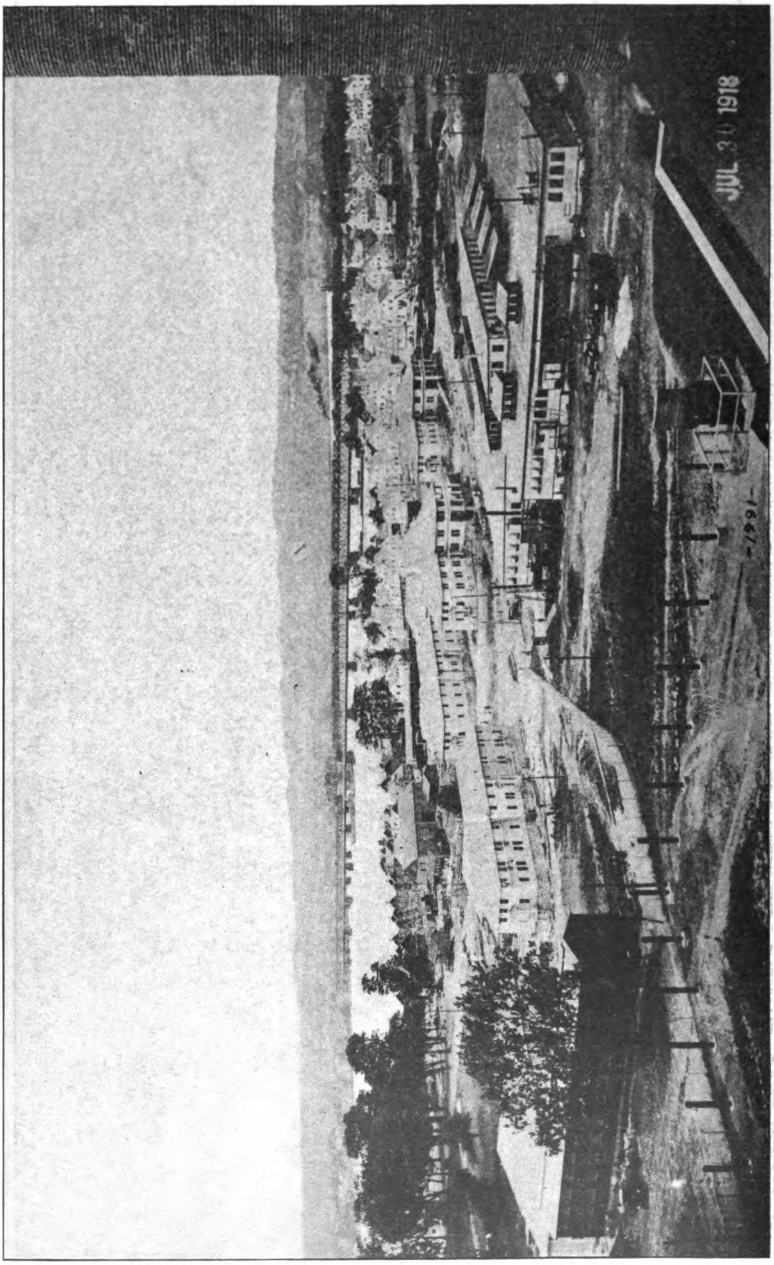


64—1



64—2

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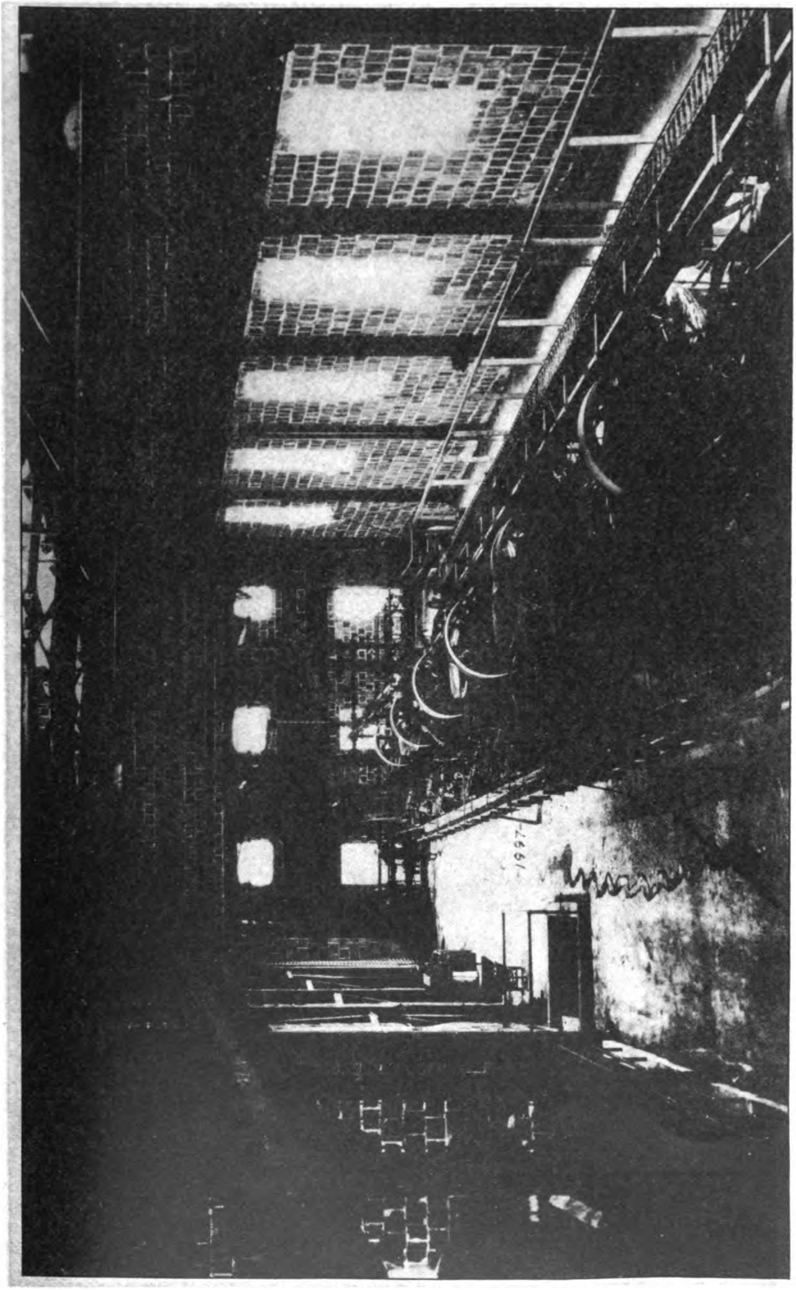

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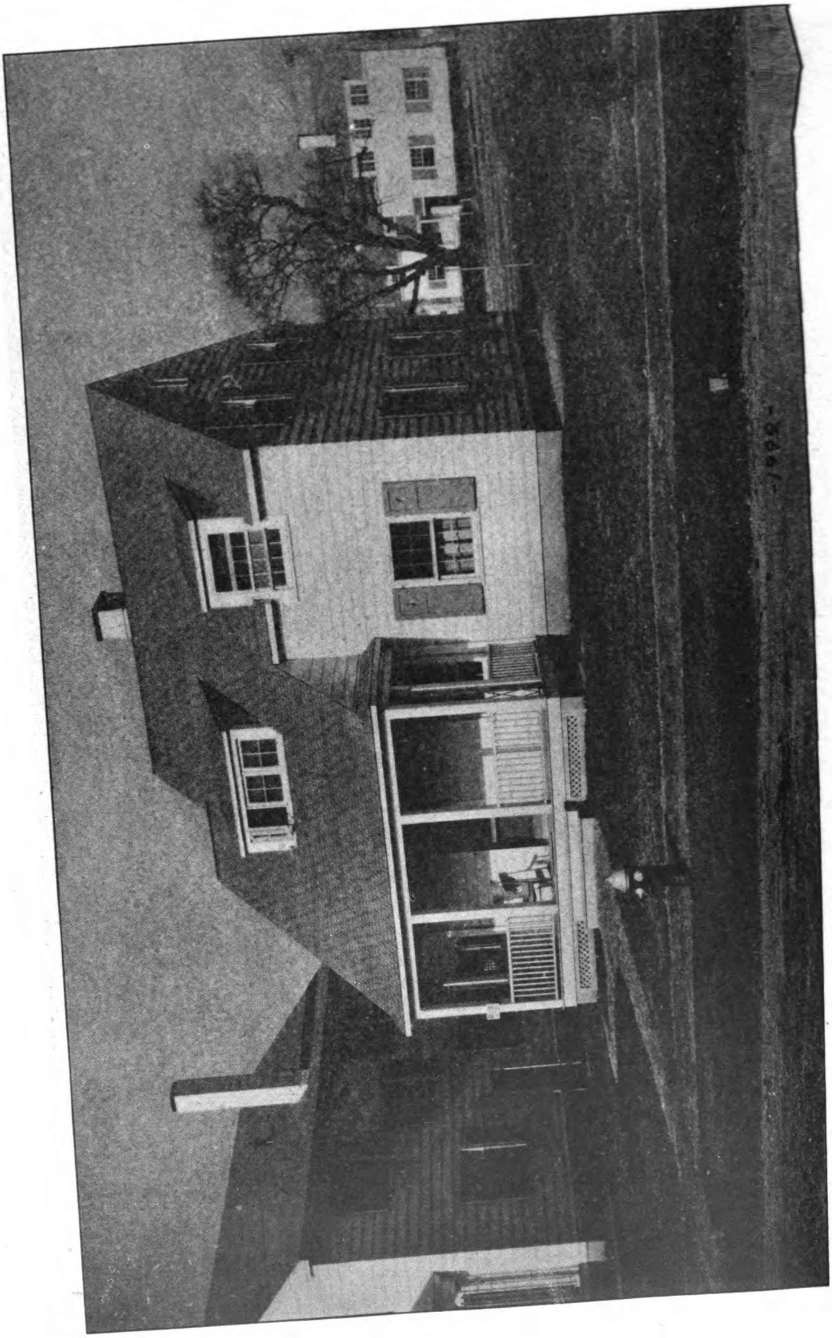

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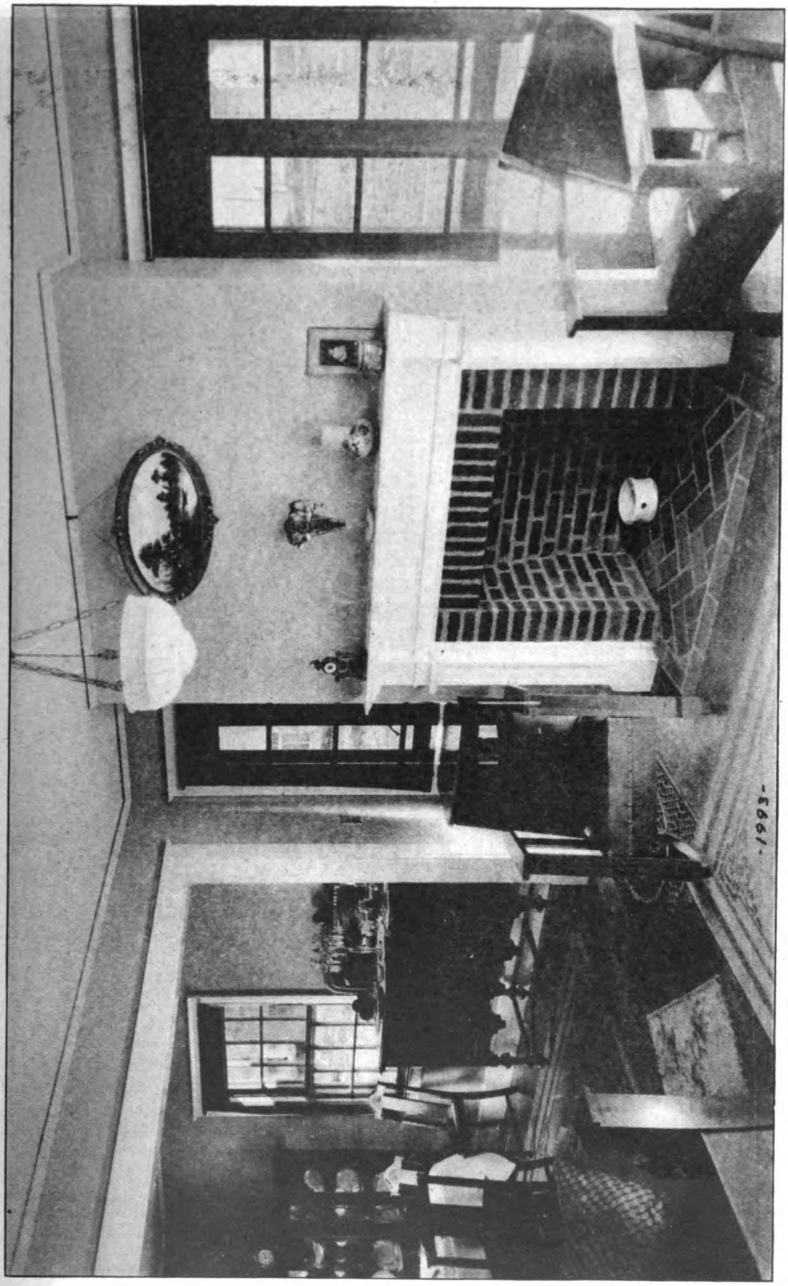

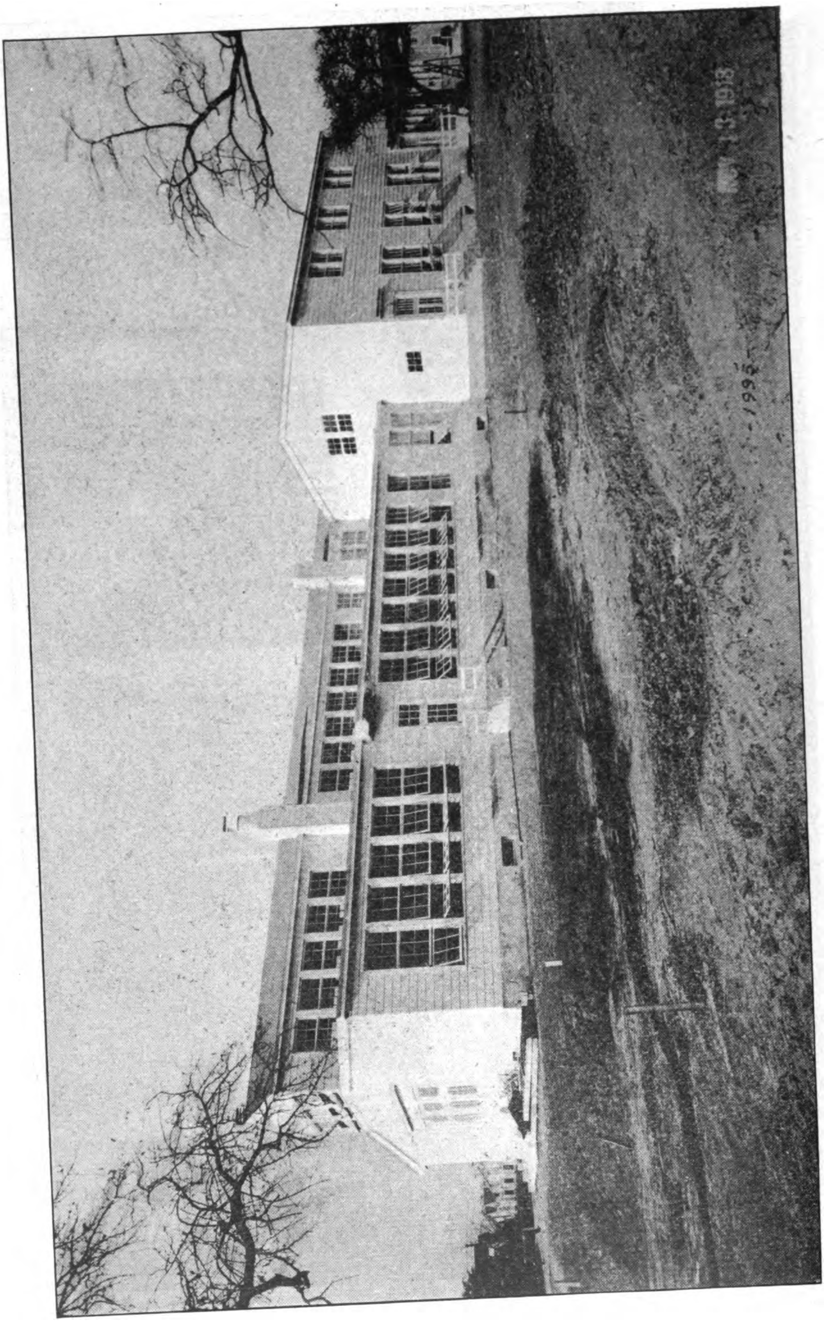

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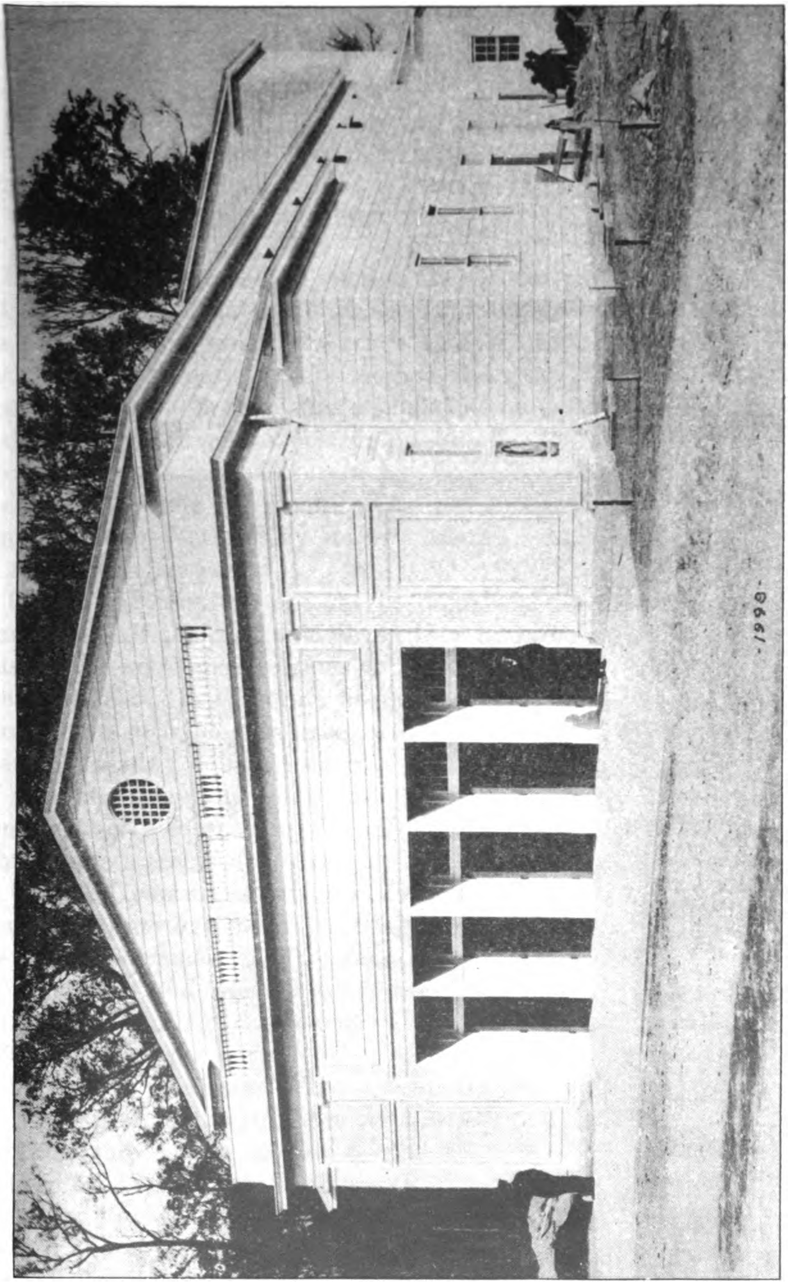


64—9

of the plant completed on the signing of the armistice, when all work was stopped.

Location.	Capacity (pounds per month).	Total cost to complete.	Per cent completed.
Giant, Calif.	2,000,000	$3,500,000	10
Racine, Wis.	4,000,000	11,118,000	5
Perryville, Md.	2,000,000	7,600,000	0

These plants were all to operate the "three-stage" process. The only big improvement made in the manufacture of T. N. T. was in the method of refining. The crude T. N. T. was to be given a wash with sodium sulphite. This method did not require an elaborate plant, and although there was a small loss of T. N. T. it was cheaper and faster, the average price paid by the United States Government to private manufacturers for T. N. T. for military purposes averaging 50 cents per pound. The cost of this material to the Government, manufactured by its own plants, was to have been from 27 to 35 cents per pound.

To get .the required amount of ammonia the Government commandeered all the ammonia; even then a shortage of this material was shown, so the air nitrates program was made. This called for the erection of the Government-owned nitrogen fixation plants. At these plants nitrogen was to be taken from the air and nitric acid and ammonia made. With all the care that was used to guard the supply of ammonia there was a shortage in August that curtailed production considerably. To guarantee a sufficient supply of ammonium nitrate while these nitrogen fixation plants were being built, it was decided to build a Government plant at Perryville, Md. This plant was to have a capacity of 600,000 pounds per day of ammonium nitrate and cost the Government $14,000,000. It was built in four and one-half months' time and was operated by the Atlas Powder Co. At the time of the signing of the armistice it was producing at the rate of 450,000 pounds per day.

This plant was using what is known as the "direct" or double-decomposition method of ammonium nitrate manufacture. Here ammonium sulphate from the coke ovens was mixed directly with sodium nitrate. This method saved the sulphuric acid that would be necessary to change sodium nitrate to nitric acid. The plant made a good product and the costs were low.

This plant, known as the United States ammonium nitrate plant, deserves special mention for the reason that its construction was completed, and that it is typical of the high-explosive plants in general built by the United States Government. Ground was broken March

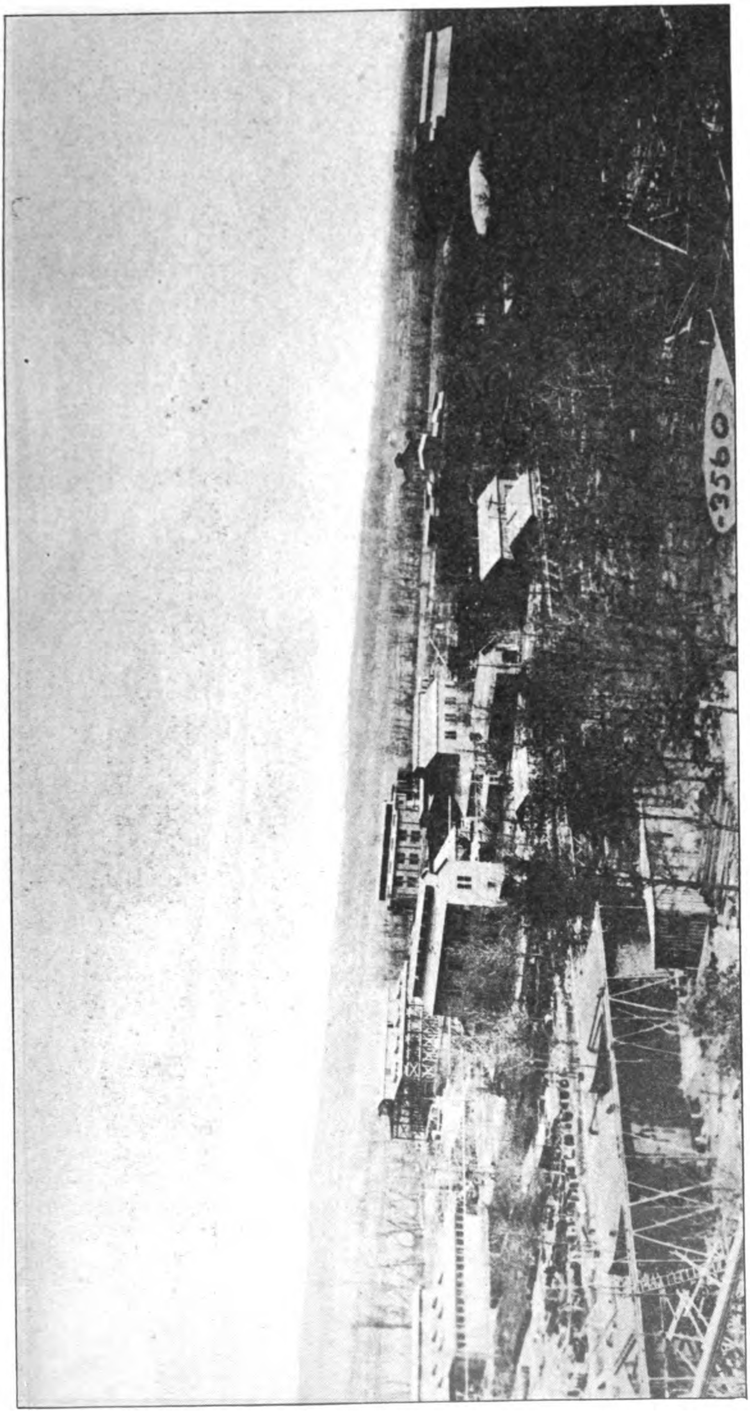
4 and production started July 20. The construction of this plant involved the construction of a village of over 300 modern cottages schoolhouses, moving-picture theaters, clubhouses, bachelors' quarters, barracks for the guards, and quarters for common labor. It was also necessary to construct a complete water purification system to treat water for domestic consumption and for plant purposes. The accompanying photographs give some idea of the magnitude of this project. After the plant had been in operation but a short time its product proved to be of such quality that it made an exceedingly high grade explosive material. Had operations continued a few weeks longer its capacity would have exceeded the original estimate. The construction and operation of this plant is looked upon as a fine achievement in the manufacture of high explosives for military purposes. Special mention is made of the assistance given by the British ministry of munitions and the Brunner Mond Co., of Great Britain, by placing the patents and a great amount of information at the disposal of this Government.

It should be borne in mind that the method most commonly used in this country for the manufacture of ammonium nitrate is what is known as the neutralization process in which nitric acid is neutralized by ammonia. Three grades of ammonia were used, namely, dynamite liquor, cyanamid ammonia, and ammonia obtained in large quantities from coke ovens. There were 21 neutralization plants in operation at the time of the signing of the armistice.

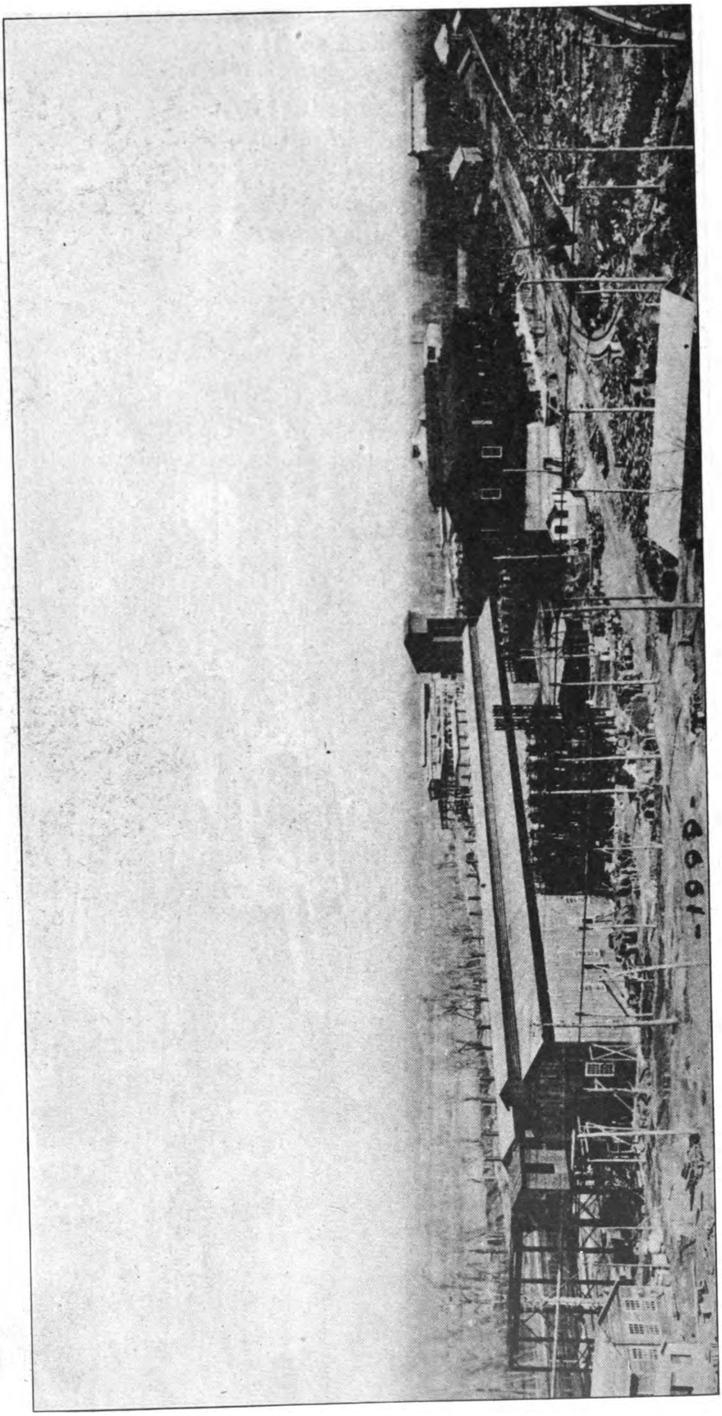
Three government-owned picric acid plants were to be built to supply picric acid to the French Government. The following table shows the location, the capacity in pounds per month, the total estimated cost, and the per cent of the plant completed when work was stopped on the signing of the armistice.

Location.	Capacity (pounds per month).	Total cost to complete.	Per cent completed.
Little Rock, Ark.	3,500,000	$[illegible]400,000	93
Brunswick, Ga.	6,000,000	13,[illegible]00,000	59
Grand Rapids, Mich.	5,000,000	9,000,000	38

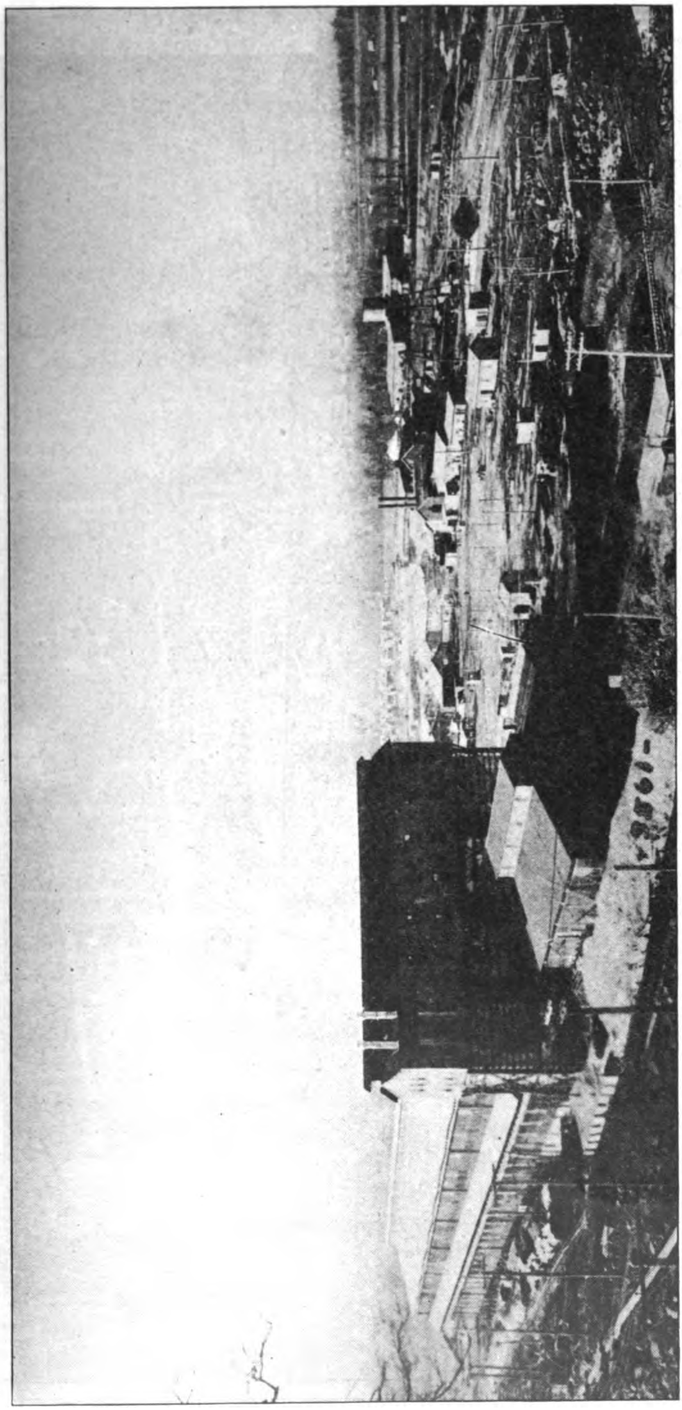
These three plants were to use the phenol process. (Attached are photographs of the picric acid plant at Little Rock, Ark.) Another system of manufacture used at two small plants is known as the chlorbenzol process. It is as follows: First, manufacture of chlorine by the electrolysis of salt solution; second, manufacture of monochlorbenzol by the action of chlorine on benzol in the presence of a catalyst; third, nitration of monochlorbenzol to dinitrochlorbenzol;



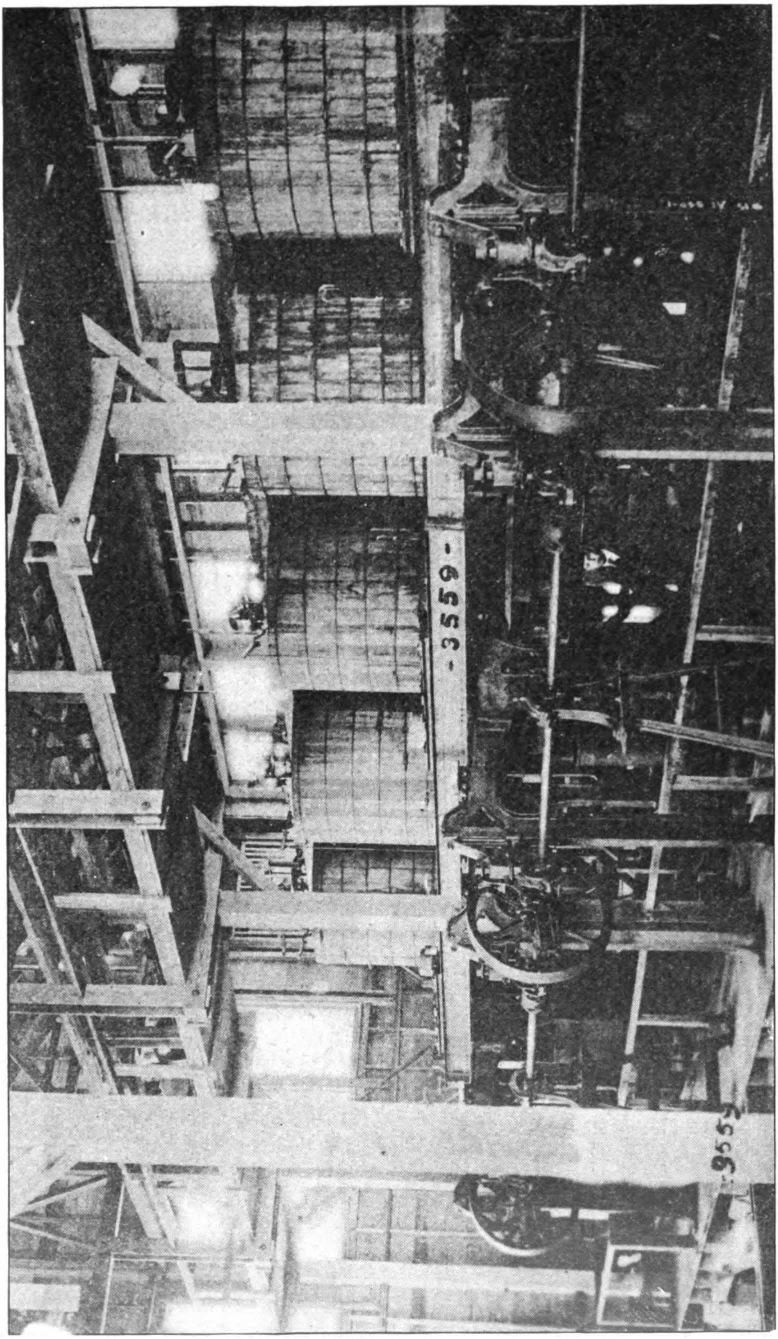
66—1



66—2



66—3



66—4

fourth, the hydrolysis of this to sodium dinitrophenolate; fifth, neutralizing this to dinitrophenol and nitrating it to picric acid.

Some experimental work was being done to nitrate phenol to picric acid by the addition of sodium nitrate instead of using nitric acid. No great advantage has been proven for it up to the present time.

The capacities of ammonium picrate plants were increased during this period, but no methods other than those which have been mentioned were developed.

In the summer of 1918 it was shown that the capacities of the two plants manufacturing tetryl were not enough to keep up with the increased requirements for this material, so a Government-owned tetryl plant was decided on. This plant was to be located at Senter, Mich., and have a capacity of 250,000 pounds per month; it was to cost $800,000 and was but 13 per cent complete on the signing of the armistice.

The capacities of the mercury fulminate plants operating were more than sufficient to supply the requirements. At the time of the signing of the armistice, three plants were engaged in the manufacture of mercury fulminate on ordnance contracts. One of these had just been rebuilt, the capacity being greatly enlarged.

As a result of the greatly increased demand for high explosives for booster purposes and due to the fact that tetranitroaniline had been shown to be a satisfactory material for this purpose, the Government ordered the construction of a plant with the capacity of 250,000 pounds per month to be built at Bound Brook, N. J. When the armistice was signed this plant was 96 per cent complete and cost in the neighborhood of $4,000,000. There was no production, except one run which was experimental. The process of manufacture can be divided into four steps: First, nitration of benzene to dinitrobenzene; second, the reduction of dinitrobenzene to metanitroaniline; third, sulphonation of metanitroaniline to metanitroaniline sulphate; fourth, nitration of metanitroaniline sulphate to tetranitroaniline.

At the beginning of the war, when it was certain that there would be a considerable shortage of toluol for the manufacture of T. N. T., pending the construction of new toluol recovery equipment, experiments were carried out upon a number of substances to determine their suitability as substitutes for T. N. T. Among these was nitrostarch powder. Nitrostarch mixtures had been used previous to the entry of this country into the war as commercial powders for mining and blasting work, but nitrostarch was unknown as a military explosive. Experimental work on this material, carried out under the direction of the Engineering Division, showed it to be a most satisfactory substance for the bursting charge of hand grenades and trench-mortar shell, and in accordance with the results obtained it was adopted as a standard military explosive for trench warfare purposes. A number of companies attempted to develop nitrostarch powder but only one was successful. This company was given large contracts and was assisted by the Government to construct its plant by adding a complete amortization allowance in the cost price of the material. This material not only proved itself to be an efficient substitute for T. N. T. and amatol but was much less expensive than these materials. The process of manufacture was kept more or less secret, but in the main it may be said to consist of: First, the nitration, washing and drying of tapioca starch; second, the mixing of nitrostarch with dried sodium nitrate and ammonium nitrate, finely divided charcoal, diphenylamine, sodium bicarbonate, and a small amount of heavy hydrocarbon oil. There was a shortage of this material during the latter part of October and November during which time 80/20 amatol was substituted for it in rifle grenades. Production at the time of the signing of the armistice was proceeding at the rate of about 4,500,000 pounds per month and would have reached within a very short time the maximum production of 5,000,000 pounds, working 8 hours per day. In case the requirements would have demanded, facilities were available for producing 15,000,000 pounds per month, working 24 hours per day.

Lyconite was developed by the E. I. du Pont Co. and consisted of sodium nitrate, nitrocotton, and small amounts of other organic compounds. About 1,000,000 pounds of this explosive were manufactured, and were used in drop bombs, but the company had trouble in getting a supply of cotton, which was much needed at that time for the manufacture of smokeless powder. Later it was found that sufficient nitrostarch, or amatol, which was cheaper, was available, so no further contracts were placed.

Ammonium chloride was produced for use as smoke producer in shell filled with 80/20 amatol.

In summing up the production of high explosives special mention should be made of the great quantities of explosives that were being made per month at the time of the signing of the armistice in comparison with what was being manufactured before this country entered the war.

Also, mention might be made of the great saving in costs; for instance, foreign Governments paid as high as $1.25 per pound for T. N. T., while the average cost to the United States Government was near 50 cents.

A great deal of credit for this is due the Ordnance Department, which recommended Government control of all raw materials, helped to standardize the processes, insisted on a strict accounting by the manufacturing plants of all raw materials used, insisted on safety measures which decreased the number of accidents that would cut down production, and helped the explosive manufacturers in solving many of their troubles. At all times, except in the case of grenade powder, the production of high explosives was much ahead of consumption. The grenade powder shortage was only temporary and there was at all times plenty of T. N. T. which could be substituted for it.

Eight main features bearing on the production and manufacture should be mentioned:

(*a*) Adoption of amatol.
(*b*) Air nitrates program.
(*c*) Construction of the Perryville plant at a cost of $14,000,000 to supply ammonium nitrate until the air nitrates plants would operate.
(*d*) Manufacture of nitrostarch powder as principal explosive for trench warfare.
(*e*) Construction of Government T. N. T. plants at a cost of $22,218,000 to produce T. N. T. for amatol program.
(*f*) Construction of Government picric acid plants at a cost of $30,000,000 in order to supply France with finished product and thus save cargo space used up by bulky raw materials.
(*g*) Commandeering of raw materials and supervision of production and distribution of same.
(*h*) Government financial aid given to private manufacturers of explosives.

The following tables are self-explanatory and bring out more clearly the enormous quantities of high explosives manufactured and the rapid increase in production.

Production, in pounds, per month of explosives for military purposes in the United States and Canada.

	Before August 1914 (estimated.)	April, 1917 (estimated).	October, 1918 (actual).	July, 1919 (estimated).
T. N. T	15,000	4,500,000	16,968,922	28,650,000
Ammonium nitrate	None.	6,000,000	21,595,934	70,000,000
Picric acid	15,000	2,100,000	4,754,698	25,000,000
Ammonium picrate	25,000	225,000	1,450,000	1,500,000
Tetryl	None.	55,000	235,000	385,000
Fulminate of mercury	None.	40,000	95,000	95,000
T. N. A	None.	None.	None.	250,000
Nitrostarch	None.	None.	1,900,000	5,000,000
Lyconite	None.	None.	500,000	1,000,000

Table showing number of plants operating or under construction at the time of the signing of the armistice.

	Privately owned.	Partly Government financed.	Government owned, operating.	Government, under constuction.	Total.
T. N. T.	6	3		3	12
Ammonium nitrate	23		1		24
Picric acid	8		2	2	12
Ammonium picrate	4				4
Tetryl	2			1	3
T. N. A				1	1
Fulminate of mercury	3				3
Nitrostarch		1			1
Lyconite	1				1
Ammonium chloride	2				2

Total production, in pounds, and average price per pound of high explosives from April, 1917, to stopping of plants after signing of armistice.

	Production (pounds).	Average price per pound.
T. N. T	113,090,507	$0.50
Ammonium nitrate	117,129,419	.17
Picric acid	43,998,45[illegible]	.55
Ammonium picrate	13,467,300	.64
Tetryl	1,340,075	.90
Fulminate of mercury	351,[illegible]03	3.17
T. N. A	17,302	1.90
Nitrostarch	8,848,855	.235
Lyconite	1,120,0[illegible]3	.28

LOADING OF HIGH EXPLOSIVES INTO ARTILLERY AMMUNITION.

The operations conducted in the United States in the loading of high explosives into ammunition cover the loading of high-explosive shell, drop bombs, shrapnel, fuzes, detonators, primers, and boosters. As the major part of the work, from the standpoint of the money involved and the difficulty of accomplishment, resides in the operation of loading the high-explosive shell and assembly of the various components to the shell, the greater part of this subject will deal with this particular phase of the work, but from this an idea may be obtained as to the corresponding efforts required in conducting the operation of loading the other components. This will naturally divide itself into two periods: First, that up to the entry of the United States into the European war; and, second, that covered from the declaration of war by the United States to the signing of the armistice.

LOADING PRIOR TO APRIL, 1917.

Prior to the beginning of the European war in 1914 the subject of loading high-explosive shell was practically undeveloped. The experiences of the British Army in the South African War led artillerists to the opinion that shrapnel was without doubt a more effective form of ammunition than high-explosive shell, so the subject of loading high-explosive shell had not been given much attention. The experiences gained during the Russo-Japanese war had served only partially to change this point of view, as is evidenced by the fact that during the first few months of the European war the British and French armies relied largely on shrapnel, although there was an insufficient supply of this, as of all other kinds of artillery ammunition. The Germans apparently had gone more fully into the subject of the use of high-explosive shell and into its manufacture, and therefore were suitably provided with this form of ammunition.

When it was found that the conditions of modern warfare as carried out on the western front demanded large quantities of artillery ammunition of all kinds, and particularly high explosive, the Allied Governments found it necessary to place large orders for this material with private contractors in the United States. The Russian and British Governments in particular secured ammunition in this way. As a result, there were erected in the United States several factories for the loading of the various components of artillery ammunition. Among these may be mentioned the factory of the Canadian Car & Foundry Co., at Kingsland, N. J.; the T. A. Gillespie Co., at Parlin, N. J.; the American Can Co., at Kenilworth, N. J.; and the E. I. du Pont de Nemours & Co., at Penniman, Va. These factories were devoted largely to the production of small caliber ammunition, which was needed in enormous quantities, such as the 3-inch and 75-millimeter, both shrapnel and high explosive. The quantities turned out were considerable, running into several millions of rounds in the case of some of the plants which ran for the longest time.

With high-explosive shell the loading was confined to cast T. N. T., an explosive which had been developed a few years prior to the war, particularly in Germany. The fact that the explosive could be made direct from toluene, obtainable in large quantities from gas manufacturers, by nitration gave it an advantage over picric acid, which requires in time of war the manufacture of synthetic phenol.

In addition to the private manufacturing facilities existing in the United States, partly as a result of the orders placed by the Allied Governments, the United States Army had conducted the loading of artillery ammunition on a very limited scale. Frankford Arsenal was the principal place where this was carried out, where there was a staff of about 500 civilians, and the production was possible of 2,000 rounds daily of shell and shrapnel for target practice and as a stock of reserve ammunition. The purpose of this manufacture had been purely for supplying the running needs of the Army for peace-time purposes, and little or no experience had been acquired by the Ordnance Department in the production on large scale of loaded shell.

In summary it may be said, therefore, that the status of facilities for production of loaded artillery ammunition in this country at the entry of the United States into the war was represented by approximately 13 privately owned corporations loading artillery ammunition for the European Governments, these plants being mostly of rather limited size, and the Government arsenals—Frankford, Picatinny, and Rock Island—which were carrying on a very limited production of loaded ammunition. From the standpoint of practice, the privately owned factories, for various reasons, were confining their loading to small caliber point fuzed shell, with straight T. N. T. as the filling, while the Government arsenals were loading the American type of base fuzed shell largely with Explosive "D" by the press method.

While this report is not intended to cover the question of engineering practice, there are some important features which are so tied up with production that mention must be made of them here. Among others was the situation in the United States prior to the outbreak of the war with reference to explosives for shell. Some experiments had been conducted on loading shell with T. N. T., but owing largely to the question of design of shell the results had not been altogether satisfactory, and after a temporary approval of T. N. T. for shell loading, approval was withdrawn and Explosive "D" again specified as the only filling. The operations of the private plants in the United States covered almost exclusively the loading of high-explosive shell and shrapnel, and the fuzes for shrapnel. Practically no experience had been had either by the Government or the private contractors in the loading of various other forms of ammunition, such as trench-mortar shell, drop bombs, and hand grenades.

LOADING FROM APRIL, 1917, TO NOVEMBER, 1918.

It will thus be seen that, although the existence of a fairly large number of private plants was fairly encouraging, on the whole the question of supplying the several hundred thousand rounds of ammunition per day which would be required by the Army of the United States was most difficult of solution. The situation was further complicated by the fact that the calculation of the quantity of high explosive needed to load the large number of shell demanded by our program showed a large deficit in the supply of T. N. T. This made it necessary, in addition to using every effort to increase the production of T. N. T., to adopt, if possible, some measures which would help solve the difficulty.

Fortunately this problem had already been met with and solved in Great Britain by the use of the explosive amatol in place of trinitrotoluene. The mixture of ammonium nitrate with T. N. T. obviously leads to a very great saving in T. N. T. On the other hand, however, it introduced into the United States a practice with which both the private plants and the Government arsenals were unfamiliar. The Government arsenals which had been loading had been using Explosive "D," which is loaded by a press method, and T. N. T. loaded either by press or a cast process. The private plants had been using cast T. N. T.

When, as a result of the report of a board of officers appointed for the purpose, a decision was reached to use amatol, it was necessary to take steps to convert the existing loading facilities to the use of amatol. This involved the installation of certain new machinery, and particularly the instruction of contractors and operators in the use of this new explosive.

In addition, the very large quantity of ammunition required demanded the erection in as short a time as possible of new loading plants. Accordingly arrangements were made to have erected four large loading plants by the Government to be operated by various private corporations which would act as agents for the Government, and operate the plants on a cost-plus basis. These plants were all designed to be of very large size, and of approximately the same output, namely, in the neighborhood of 40,000 to 50,000 loaded shells per day. It was necessary to select carefully the very large sites required, covering several square miles of ground, to secure this land, and then to erect the great number of buildings required for the shell-loading operation. For example, at the T. A. Gillespie Co., Morgan, N. J., there was a total of approximately 200 buildings required for the essential factory part of the work. In addition, in several of the plants, owing to the isolated nature of the work, elaborate preparations had to be made for housing facilities.

Due to the character of the work done in the various loading plants and the danger attendant upon the storage of the high explosives necessary to insure a continuous supply of materials at the plants, it was necessary that the large plants be located in sparsely settled country at a considerable distance from any cities. As a result large areas of land were purchased or rented in undeveloped localities. This necessitated the erection of quarters not only for the operating forces of the plant, but also barracks for the army of thousands of men necessary to do the original construction work.

The town of Amatol, N. J., the plant of the Atlantic Loading Co., may be taken as a representative of the towns which were built at the several loading plants, such as Mays Landing, N. J., and Penniman, Va. At Amatol the first buildings constructed were mess halls and temporary barracks. The men occupying these were employed in building several miles of railroad tracks, clearing the land and erecting buildings for both factory and town. Then there were the streets to be graded, the water system to be installed, and electric lights provided to light the streets as well as the houses which were to be built. Amatol is built in the pine country of New Jersey about 40 miles from Philadelphia and an equal distance from Atlantic City. The only town anywhere in the vicinity is Hammonton, a village of about 6,000 people, some 7 or 8 miles west of the village of Amatol.

It was expected that the population of the village of Amatol would reach seven or eight thousand persons, consequently houses of varying types as well as dormitories were built. There are dormitories for the men and dormitories for the women. There are large mess halls, two-room cottages, three-room cottages, houses ranging from four to six rooms, apartment houses containing four or five room apartments, and other houses and apartments varying in size and arrangements between these limits.

In order to keep the workers satisfied and to enable their families to live in the village without too great a desire to move to more interesting localities, it was necessary to provide recreation in various forms as well as the conveniences which could make the town habitable. The following list ennumerates some of the buildings which were erected in addition to the houses and dormitories: Gaming hall, writing room, theater seating 750 people, clothing store, shoe store, barber shop, drug store, steam laundry, fruit store, post office, mercantile store, assembly and dance hall, an eight-room school building, a church, and fire house. In addition to these buildings, other towns, like Penniman, Va., provided Young Men's Christian Association buildings for both white and colored men, and Young Women's Christian Association buildings, as well as railroad stations, freight shops, public garages, and quick-lunch rooms. Penniman also possesses a jail.

The plant of T. A. Gillespie Loading Co., agents, Morgan, N. J., occupied an area of 7,680 acres of land. The total cost of the plant and buildings was $17,867,000. The plant was originally designed to load shell as follows:

	Per month.
75-millimeters	625,000
4.7-inch	125,000
155-millimeters	300,000
8-inch	100,000
3-inch Stokes TMS	500,000

Construction began the 15th of January, 1918, and loading operations actually commenced the 15th of June, 1918, which, considering the size of the plant, labor conditions, and the severity of the winter of 1917–18, was a remarkable achievement. The plant continued production on a rapidly increasing scale, new units being added from time to time, until October 4, 1918, when the entire plant was destroyed by explosion. During the period which it operated the plant had produced loaded shell as follows:

	Per month.
75-millimeter	75,700
4.7-inch	14,124
155-millimeter	355,643
8-inch	54,956
3-inch Stokes TMS	498,114

The plant was designed to load with both 50/50 and 80/20 amatol. Owing to the shorter time required to install the former process, the operation had been confined to this during the first month or so after operations began. However, the 80/20 units were rapidly made ready, and at the time of the disaster large production of shell loaded with 80/20 amatol was being obtained.

On October 16, 1918, in compliance with Office Order No. 356 and with Office Order No. 452, a board of officers was appointed to investigate and report on the causes and extent of the damage occasioned by the explosion. The findings of the board were submitted, with recommendations for the prevention of a similar occurrence. On November 5 and December 11, 1918, in accordance with Office Orders Nos. 383 and 417, a committee of officers was appointed to attend the hearings of the Senate committee on this matter, and on November 5, 1918, there was appointed, according to Office Order No. 385, a board to determine the amount due on claims for damage and loss of private property caused by the explosion and fire.

The plant of the Du Pont Engineering Co., agents, Penniman, Va., occupied 5,114 acres of ground. The cost of the plant was in the neighborhood of $14,000,000, of which $3,000,000 had to be expended for housing of operators. As originally designed, it was intended to load shell as follows:

	Per month.
75-millimeter and 4.7-inch	625,000
155-millimeter	300,000
8-inch	100,000
Boosters	1,250,000

Construction began March 1, 1918, and operations commenced on June 20, 1918, which was again a remarkable achievement, considering the large size of the plant and rather isolated situation. The production up to the time of the armistice was:

	Per month.
75-millimeter and 4.7-inch	313,740
155-millimeter	164,880
8-inch	182,082
Boosters	748,300

At this plant, owing to the climatic conditions, considerable trouble was experienced with the use of amatol, particularly in warm weather. However, these difficulties were rapidly overcome. In addition, owing to its isolated situation, labor shortage was acute, which led eventually to the use of military personnel in the factory.

The plant of the Bethlehem Loading Co., agents, Mays Landing, N. J., covered 5,000 acres of ground, and as originally laid out the cost was estimated to be $19,423,000. In the case of this plant it was necessary to spend approximately $4,000,000 to provide suitable housing for the operators and officials. The original design of the plant called for production as follows:

	Per month.
75-millimeter	625,000
155-millimeter	300,000
8-inch	100,000

Construction began March 1, 1918, and operations began September 15, 1918, so that the plant was operated for a short time only prior to the signing of the armistice. During this time the loading was chiefly the 155-millimeter and 75-millimeter shell.

The fourth of the large Government plants was that of the Atlantic Loading Co., agents, Amatol, N. J., which covered 6,000 acres of ground, and of which the estimated cost to complete was $17,066,000. The plant was designed to turn out shell as follows:

	Per month.
75-millimeter	625,000
4.7-inch	175,000
155-millimeter	300,000
8-inch	100,000
Boosters	500,000

At this plant considerable difficulty was met with in both the construction and the operation of the plant, owing to labor shortage. The total production up to the time of the signing of the armistice was limited to 75-millimeter shell, of which 313,732 had been loaded.

In addition to these Government plants, the private plants, to which reference has already been made, were, at the entry of the United States into the war, given contracts for loading ammunition for the United States Government. In addition to the private plants already in existence which had been built to work on European contracts, there were several other loading plants erected. One of these was that of the Evans Engineering Co., Old Bridge, N. J. The construction of this plant began in July, 1917, and operations actually commenced November 14, 1917, on the loading of high-explosive shell. At this time cast T. N. T. was used as the filling, but later 50/50 amatol was adopted. The total quantity of shell loaded at this plant up to the signing of the armistice was 2,059,677.

The T. A. Gillespie Co., at Parlin, N. J., had received contracts for loading 75-millimeter shell, and loaded a total of 2,288,825 and here again the operation had begun with straight T. N. T., but later changed to amatol.

The American Can Co., Kenilworth, N. J., which has already been referred to as operating on Russian contracts, received contracts from the United States Government, and up to the signing of the armistice delivered approximately 4,000,000 rounds of shrapnel and 802,000 rounds of 75-millimeter high-explosive shell.

The T. A. Gillespie Co. at Runyon, N. J., had also been operating on the Russian contract prior to the entry of the United States into the war. In August, 1917, they were given a contract by the United States Government and started production early in 1918. Up to the signing of the armistice they had delivered to the Government the following shell:

4.7-inch	28,000
6-inch	73,000
6-inch gun	61,200
155-millimeter howitzer	239,000
9.2-inch howitzer	10,000

The E. I. du Pont de Nemours & Co. had a plant loading shell on European contracts at Penniman, Va. They were awarded in October, 1917, a contract to load shell for the United States Government, and went into production in January, 1918. During the time of operations up to November 30, 1918, they had delivered to the Government the following:

75-millimeter	140,000
3-inch	400,000
4.7-inch	103,000

The Bartlett Hayward Co., Baltimore, Md., was given contract for loading shrapnel. Up to November 30, 1918, they had delivered to the Government the following:

75-millimeter shrapnel rounds	3,563,000
4.7-inch shrapnel rounds	450,000
155-millimeter shrapnel rounds	363,000

The Bethlehem Loading Co. operated plants at Reddington, Pa., for loading point-fuzed shell, and at New Castle, Del., for loading base-fuzed shell. The former plant up to the 30th of November had delivered 125,000 8-inch and 9.2-inch shell. At the New Castle plant the large caliber base-fuzed shell were loaded by the press process, and 75,000 10-inch loaded with Explosive " D " were delivered up to November 30, 1918. In addition 3,286,000 boosters were loaded at this plant.

In addition to these private plants and agencies the Government arsenals also engaged in shell loading.

At Rock Island Arsenal, Rock Island, Ill., just prior to the entrance of the United States into the war, a shell-loading plant for loading cast T. N. T. had been erected. Up to November 30, 1918, this arsenal had delivered to the Government 242,000 155-millimeter high-explosive shell.

At Picatinny Arsenal, Dover, N. J., the loading was confined to pressed Explosive "D" filling for large caliber shell, and up to October 11, 9,304 10-inch shell had been loaded.

At Frankford Arsenal, Philadelphia, Pa., up to November 30, 1918, there had been loaded and delivered to the Government 43,500 2.95-inch mountain gun shrapnel, 303,000 75-millimeter shrapnel, 30,000 3-inch antiaircraft shrapnel, 15,000 3.8-inch howitzer shrapnel, 23,000 4.7-inch howitzer shrapnel, and 955 6-inch howitzer shrapnel, 20,000 3-inch gun, 11,000 3.8-inch howitzer, 6,000 4.7-inch gun, 12,600 4.7-inch howitzer, 8,400 6-inch howitzer high-explosive shell.

From the foregoing an idea can be obtained as to the magnitude of the operations involved in loading artillery ammunition for the American Army. The following table shows the total production of the various components up to the signing of the armistice, and will give some idea of the extent to which the United States succeeded in performing the duty imposed upon it.

Shrapnel rounds.

2.95-inch mountain gun	91, 820
75-millimeter	7, 865, 458
75-millimeter anti-aircraft	507, 643
3-inch gun	40, 000
3-inch anti-aircraft	30, 164
3-inch field gun	2, 048, 697
3.8-inch howitzer	11, 757
4.7-inch howitzer	60, 787
4.7-inch gun	257, 356
155-millimeter gun and howitzer	159, 193
6-inch howitzer	3, 826
Total	11, 076, 701

High-explosive shell.

37-millimeter L. E.	4, 060, 411
75-millimeter	6, 556, 491
3-inch field gun	1, 070, 902
3-inch 15-pounder	879
3.8-inch howitzer	11, 750
4.7-inch gun	124, 653
4.7-inch howitzer	39, 198
5-inch seacoast gun	14, 124
155-millimeter howitzer	1, 101, 611
155-millimeter gun	47, 927

High-explosive shell—Continued.

6-inch gun	61,869
6-inch howitzer	107,327
8-inch howitzer	193,200
8-inch gun	138,625
9.2-inch howitzer	170,608
10-inch seacoast gun	74,537
Total	13,774,112

Point detonating and time fuzes.

Mark I	500,991
Mark II, short delay	77,070
Mark III	7,892,095
Mark IV, nondelay	50,180
Mark IV, short delay	526,340
Mark V, nondelay	2,472,200
Mark V, short delay	443,280
Mark VI	1,699,860
21-second time fuze	3,603,876
21-second anti-craft 75-millimeter	640,000
21-second 3 inch anti-aircraft	41,840
31-45 time fuze	463,444
Mechanical time fuze	11,100
Base percussion, 37-millimeter	4,000,000
Total	22,422,276

Boosters for high-explosive shell.

Mark I	454,385
Mark II	410,594
Mark III, 75-millimeter	6,574,811
Mark III, 155-millimeter	1,956,178
Mark IV	982,173
Mark V	4,735
240-millimeter	18,031
Total	10,400,907

Mention has already been made of the difficulties arising from labor shortage. A further difficulty from the standpoint of operation arose from the fact that during the entire period extensive construction work was being carried out alongside of regular operation in the plants.

A further difficulty, inherent to the problem, is that of arranging for the flow in proper quantities of the various components to the plants. The loading of artillery ammunition is both a manufacturing and an assembling process. The manufacturing part presents difficulties of its own owing to the dangerous nature of the materials and to the importance of conducting the operation with uniformity and attention to small details. In addition, to securing production of loaded and assembled rounds, a supply of all the necessary components is needed. Thus to assemble shell, loaded boosters are needed; to load boosters, obviously the metal parts of the boosters are needed, so that the entire operation from the foundry and machine shop to the loading plant is really one huge machine every part of which must be functioning properly to secure good results.

Difficulties were experienced from both of these factors, but were rapidly overcome and at the time of the signing of the armistice all plants were getting into full production.

ASSEMBLY OF PROPELLANT CHARGES.

For all guns up to and including 4.7-inch, fixed ammunition is required; that is, the charge is inclosed in a cartridge case. All fixed ammunition was assembled at the shell-filling plant where it became necessary to install storage capacity and equipment to handle the propellant powder as well as fill the high-explosive shell.

Guns of 5-inch and over require separate loading ammunition, which means that the powder charges are loaded into cartridge bags at bag-loading plants and packed into cartridge storage cases until ready for use.

Prior to our entrance into the war all separate loading powder charges were manufactured at Picatinny Arsenal. This included the manufacture of the bag and the complete assembly into a powder charge. At that time the arsenal had a capacity for the manufacture of approximately 300 bags per day.

The actual loading operation was not complicated, but the method as first employed required considerable time. The complete cartridge bag, including lacing twine and data tag upon which was printed the ballistic data as determined by the ballistic test for acceptance of the powder lot, was first weighed and the weight marked on the bag to avoid error in filling. The net charge required was weighed and the bag filled through an opening in one end, the opening being closed by hand sewing when the proper amount of powder had been put in.

The bag was then laid on a table or smooth floor and rolled to give a compact form and a uniform diameter and was then ready for lacing. As the bags were larger in diameter than was required for the charge, this lacing was necessary to give the charge a rigid form which would not be lost in handling. This lacing was done by hand with a needle issued for the purpose. After the lacing was completed the bag must be rolled backward and forward to reduce the diameter and to more firmly pack the powder, after which procedure the lacing was again tightened and firmly tied.

As the capacity for production of charges was entirely inadequate at Picatinny Arsenal to meet the demands of the Army in France steps had to be taken immediately to enlarge upon this capacity.

At first steps were taken looking toward the development of plants equipped to manufacture the cartridge bags and load the powder charges, but it was found unnecessary to do this as the bags could be manufactured in sufficient number and quality by commercial jobbers in New York and at a sufficiently low price to make the establishment of bag-manufacturing plants unnecessary. The Ordnance Department furnished drawings showing the design of the bags and also furnished specifications for the material to be used.

In order to provide for the increased demand for propellant charges, three bag-loading plants, namely, the Woodbury Bag Loading Plant, built and operated by the MacArthur Bros.; the Tullytown Bag Loading Plant, Tullytown, Pa., built and operated by the Du Pont Engineering Co.; and the Seven Pines Bag Loading Plant, Richmond, Va., built and operated by the Du Pont Engineering Co., were established, each having a capacity of 20,000 propelling charges per day. After operations were started on these plants it was found that their actual capacity was double their rated capacity. None of these plants were worked to their maximum capacity, however, as components were not manufactured at a high enough rate to keep them in constant operation.

The Woodbury Bag Loading Plant came into production in June, 1918, and the Tullytown Plant in August, while the Seven Pines Bag Loading Plant was just reaching production when the armistice was signed. In these three plants a total of 2,494,835 separate loading charges were manufactured during the war.

Not only were the capacities increased for manufacturing the propelling charges but the methods employed were improved to such an extent that the time required for preparing each charge was reduced to a minimum. Changes in the design of bags for separate loading ammunition was also a factor toward speeding production. Nearly all the bags in use for separate loading ammunition can be divided into four types: Type I, similar to 5-inch, 155-millimeter, and 6-inch guns; Type II, as 8-inch, 10-inch, and 12-inch guns; Type III, 155-millimeter, 8-inch, and 9.2-inch howitzers; and Type IV, 12-inch mortars and 16-inch howitzers.

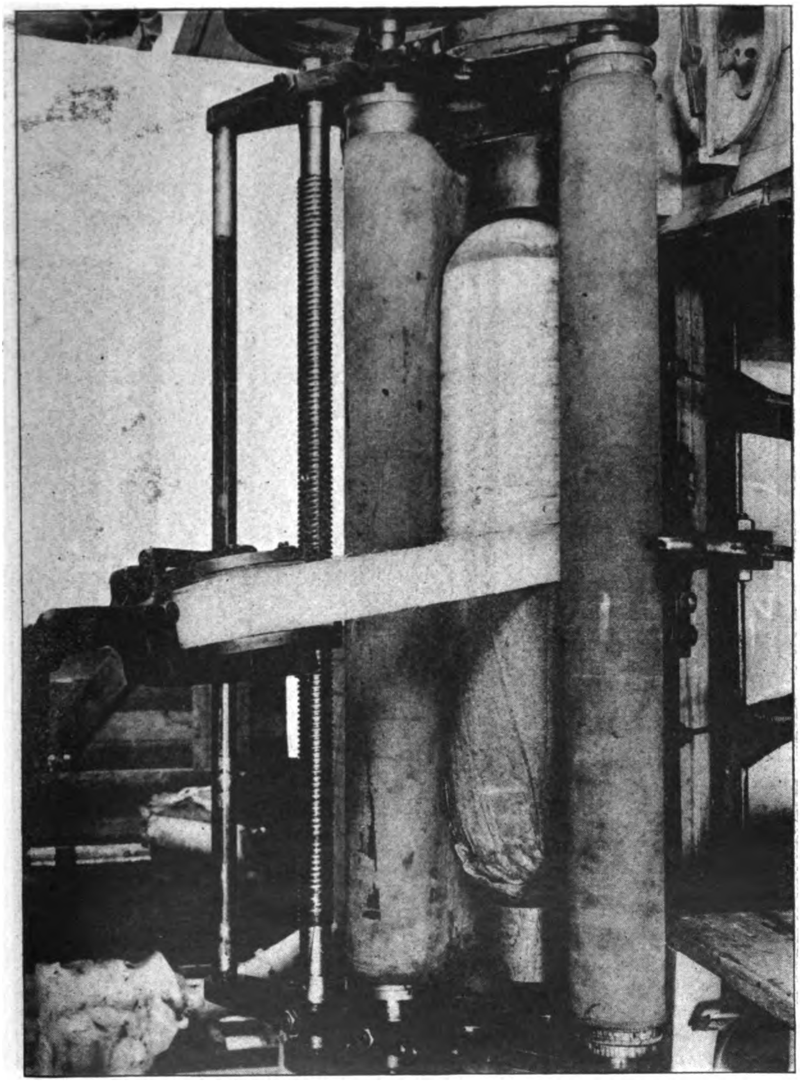
When it became apparent that a stiffer charge and more rapid production were essential than were possible if the lacing operation was retained, wrapping by means of a "special puttee" strap or wrapping strap was adopted in place of the lacing. This wrapping when done by hand was considerably quicker than the lacing operation and work was soon started on the development of a wrapping machine, the main improvements being (*a*) saving of time; (*b*) a constant tension on the tape during the wrapping; and (*c*) a uniform application of the tape to prevent loosening when the bag was handled. Following page 82 photographs are inserted which show bag in the process of being rolled and wrapped by machinery. The time consumed for this operation is about one-fifth of that required when the wrapping is done by hand by an experienced man.

The loading of a core igniter by ramming the powder in by hand was also a slow and tedious operation. While the adoption of the process of air blowing the powder in expedited the loading of the igniter, difficulty was experienced when loading the powder charge in keeping the core in the center of the charge. Because of the desire to do away with the core igniter charge, with its great difficulties in production, ballistic experiments were started early in the war to determine whether satisfactory ignition could be secured without same. Results were so satisfactory that a pancake igniter at the rear end of the base section was adopted for small guns and howitzers. This important decision led to the development of Types I and III bags. The necessity of core ignition for the larger guns and howitzers led to the designing of Types II and IV bags.

In order to prevent the absorption of moisture by the carefully weighed smokeless powder charge, which would result in a decrease in the muzzle velocity of the projectile, a container for the shipment of the charges is necessary. This must be air-tight, heavy enough, and of a suitable design so that the air-tight joint can be maintained during a long shipment. Charges for seacoast cannon in seacoast fortifications were loaded in metal cartridge storage cases.

For medium caliber mobile cannon charges a metal-lined box was first used. This, however, was not suitable for ocean shipment and a probable six months' storage. A steel container similar to that for seacoast charges was next considered but was not adopted because production facilities were not available for both the major and minor caliber mobile program, and the strong steel container was necessarily required for the major caliber charges on account of their weight. Fiber containers consisting of cylindrical tubes built of waterproofed paper with metal ends crimped on were finally adopted.

Later a steel cartridge storage case was adopted for 155-millimeter gun and howitzer and 6-inch gun charges, and orders for fiber containers in these sizes were discontinued. The new case was similar to the one adopted for major caliber mobile cannon but was of lighter steel. This was adopted because the fiber container had not proved satisfactory for these calibers and because sufficient production facilities for metal could be obtained without interfering with



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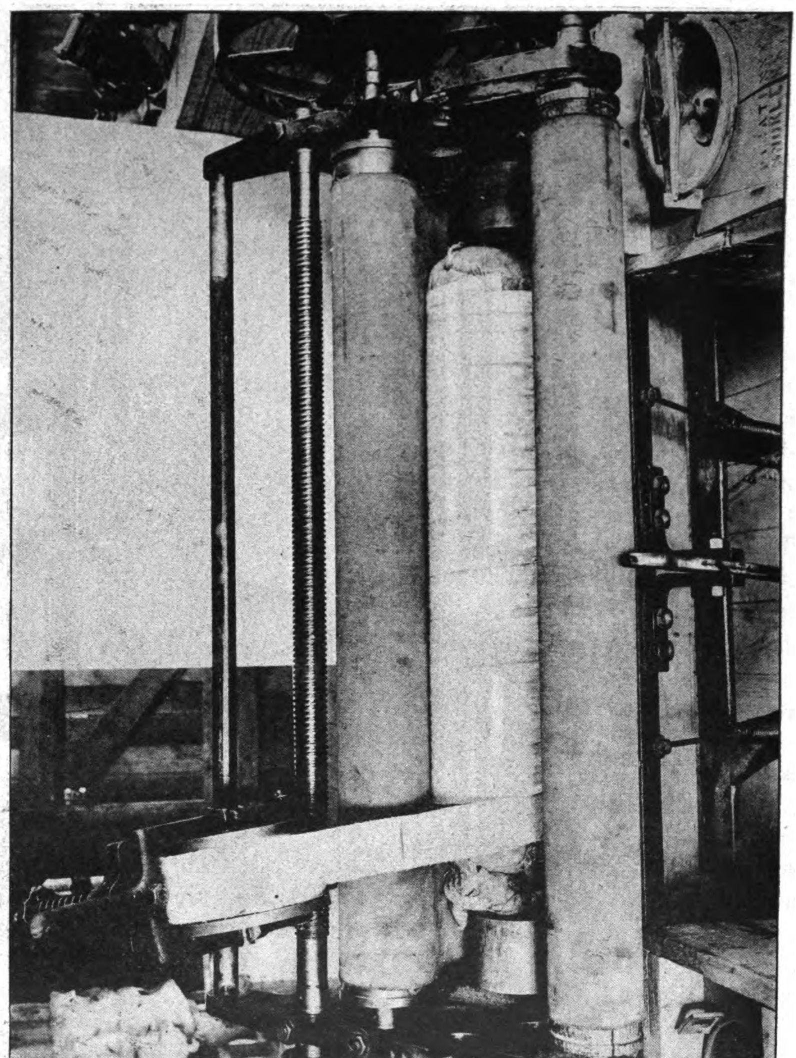

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the program for those for major caliber artillery. The advantages of the metal case over the fiber are:

(*a*) Saving of shipping space owing to the elimination of the wooden box in which fiber containers were shipped.
(*b*) Re-use of steel container while fiber container could be used but once.
(*c*) Simplifying of operations at bag loading plants due to elimination of crimping, lacquering, bagging, boxing, and strapping operations.
(*d*) Small number of rejections.
(*e*) Ease with which powder charge can be removed at the front and the can resealed if unused increment sections are to be sent back for reblending.
(*f*) Less risk of loss by fire.
(*g*) Cost of steel cartridge storage case as compared with fiber container.

After tests showing a reduced velocity and increased moisture content of charges stored in fiber containers, the Engineering Division reported this container, although suitable for short storage in war times, as unsatisfactory for long storage under peace conditions and at the recommendation of this division, the Chief of Ordnance, by office memorandum, dated December 2, 1918, authorized that no more charges be loaded in fiber and that all fiber containers already loaded be opened and the charges placed in steel.

Gun or howitzer.	Charges assembled to Nov. 14, 1918.
37-millimeter	4,060,411
75-millimeter	13,073,973
75-millimeter anti-aircraft	541,696
3-inch field gun	1,070,902
3-inch 15-pounder (98–02)	11,879
3-inch 15-pounder anti-aircraft	40,000
3-inch 15-pounder (1918)	30,164
3.8-inch howitzer	11,757
4.7-inch gun	387,176
4.7-inch howitzer (07)	99,985
5-inch wheel mount (1897)	74,491
6-inch railroad mount	179,606
6-inch howitzer (06)	50,876
155-millimeter gun	338,238
155-millimeter howitzer	1,288,281
8-inch gun, railroad mount	22,821
8-inch howitzer, Mark I–VI	300,199
9.2-inch howitzer, Mark I	212,625
10-inch gun, railroad mount	28,698

Chapter VI.

INSPECTION OF EXPLOSIVES.

The history of explosives inspection embraces the inspection from the procuring of the raw materials for the high explosives and propellants until the final acceptance of the completed round of ammunition.

HIGH EXPLOSIVES.

RAW MATERIALS.

Raw materials were accepted by the Ordnance Department upon affidavits submitted by manufacturers as to quality and quantity. Consumers were privileged to question any raw materials and the inspector would analyze or make any other checks necessary to substantiate any claims.

MANUFACTURE.

Inspection forces at the high-explosive plants were in charge of the chief inspector acting as the representative of the Ordnance Department. His duties were those of inspection, production, and property work. He was responsible for the inspection forces of the plant in every respect. His personnel was headed by a chief chemist in charge of all laboratory work, and an assistant inspector in charge of all manufacturing inspection. These men were provided with the necessary technical, nontechnical, and clerical assistants. The total number of inspectors at a plant varied from one at the small plants to seven at the largest.

Processes of manufacture were scrutinized at all times to insure cleanliness and the nonincorporation of objectionable material, and to prohibit injurious treatments.

The first official manual covering the duties, methods of testing, specifications, etc., was the "Picatinny Arsenal Laboratory Standard Methods of Conducting Tests." This was superseded by various inspectors' manuals until finally the "Inspection Manual," for which revisions and additional pages were sent out monthly, was issued by the Washington office. This manual is to-day in effect, consists of some 200 pages, and is complete in every respect. It interprets in detail the specifications given by the Engineering Division. Standard procedure by all field operators is thus insured.

Standard samples of all materials were circulated monthly, and results obtained from the various plants closely checked to insure and increase efficiency. Traveling supervisors were maintained by the Washington office and the district offices to complete the efforts of standardization and uniformity in all procedure.

Upon completion of a lot of material, it was submitted for acceptance by the company to the inspector. Samples were taken and analyses made as specified. Description sheets were accomplished showing the results of chemical tests, weights, and general manufacturing compliance by the inspector.

Weights were determined on 2 per cent of the packed containers, a tolerance of one-quarter of 1 per cent being allowed on the total weight of the lot as submitted by the company in determining the proper payment. The inspectors telegraphed the district office regarding the results of his tests. If the material was acceptable in the opinion of the district office an informal acceptance was issued by wire. This saved approximately two weeks in the payment and shipping of material.

Upon receipt of the signed and accomplished description sheets the district office issued a formal acceptance. A copy of the formal acceptance and description sheets were forwarded to the Washington office and other copies distributed to the manufacturer, and other interested parties. The Washington office checked the data contained in these sheets to insure compliance and uniformity and to complete all necessary records. The above procedure was in force in private plants and at the Government-owned plants. Ammonium nitrate, ammonium picrate, nitrostarch explosives, mercury fulminate, picric acid, primer ingredients, T. N. T., tetryl, T. N. A., various chemicals and raw materials were handled in this way.

Acceptance tests for high explosives were intended to determine the purity, stability, physical characteristics, and percentage of constituents of the materials. Chemical and physical characteristics were in all cases controlled. Specified limits were, in many cases, set aside because of the great demand for propellants and high explosives, but marked discrepancies were never tolerated.

LOADINGS.

From the time that the shell, cartridge cases, explosives, detonators, etc., were unloaded from the cars up to the time that finished complete rounds were loaded into cars, all materials and operations were constantly under the eyes of the inspectors.

Before the system was organized, some difficulty naturally arose that had to be corrected. Firms were numbering lots of ammunition consecutively as they were presented for assembling regardless of which contract was being worked on. It was decided that on each contract the first number of the contract should be used as a key number of the lot, followed by the consecutive number as: 1090–1–2–3, etc., on Contract G 1090–583 A. Later a key letter was established to indicate the caliber. "A" represented subcaliber 1.457-inch; "B," 37-millimeter; "C," 2.24-inch; "D," 2.95-inch; "H," 75-millimeter; "K," 155-millimeter, and so on.

Numerous tests were conducted in the loading plants, such tests being made by several Government men other than the routine inspection force. Tests were made to see that the amatol as loaded was of the proper density, to see that the amatol had no more than 0.25 per cent water content, and to see that the T. N. T. used was equally distributed throughout the charge. The number and frequency of these tests depended entirely upon the uniformity of the product of each plant. For example, at plants where cavitation was frequently encountered the tests for cavitation were made with great regularity until such time as the product showed that the difficulty had been overcome. A manual entitled "Instructions to Inspectors of Shell Loading," published by the Inspection Division, contained instructions in detail on tests to be made, shipments of ballistic samples, etc., and was of great benefit to the inspectors.

Traveling supervisors were able to aid the men in the field greatly by having all the chief inspectors and their assistants in the district meet at one of the plants each week. This was the means of giving all chief inspectors the benefit of questions which had come to the attention of some one during the week. Monthly meetings were arranged of all chief inspectors and plant superintendents at which any matters of interest or any differences between the operating and inspecting forces were discussed and settled.

Ammunition was manufactured by approximately 15 companies at approximately 20 plants, and is covered by 30 loading contracts for many millions of shell and shrapnel of 10 distinct calibers.

Inspection was more rigid at Government-owned plants than at private plants, this being due to the fact that Government-owned plants started operations with the inspection force on duty, all accommodations having been made, while at the private plants inspection was a later consideration and the plants were mostly crowded to capacity by the operating force, giving the inspectors less opportunity to scrutinize the work.

The inspection forces in the field were at all times the interpreters and direct administrators of the specifications as written. Frequently it was necessary for an inspector to stretch his conscience to allow existing conditions to come within the specifications. On several occasions it was necessary to ask (through the district office) a revision of specifications. This was usually granted if within reason. The usual plea of the plant superintendents was that too high a standard of inspection was being maintained. At one time it was found necessary to ask that 75/25 amatol be accepted in place of

80/20, as it was practically impossible to procure the proper density with the latter. At times orders were received from Washington, through the district office, to "loosen up" on inspection, not entirely waiving the specifications but passing everything that the inspector thought would function. Sometimes an order of this nature would be received along with authority to waive certain provisions of the specifications; in one instance 10,000 5-inch shell were to be loaded in an unusually short space of time and to make this possible, authority was given the chief inspector to allow cavitation around the booster cavity to such an extent as would ordinarily cause shell to be rejected and retopped. Such orders always were limited to a definite number of shell or to a definite period of manufacture, and were due, of course, to exceptional demands for speed based on emergency requirements abroad.

Much time was saved in the plants by the district offices, as matters would be taken up by the district office with the Washington office and decision forwarded to men in the field more expediently than the field force could take up the same matters with the Washington office.

Following are a few of the usual difficulties encountered in the shell-loading plants and description of the means of overcoming them. Inexperience of workmen and the poor materials which were at first received in shell-loading plants were largely responsible for the initial delays. At first some difficulty was experienced with ammonium nitrate, as that which was manufactured by some private concerns was far from uniform. Two lots of the same material used under similar conditions throughout could never be depended upon to give the same density. This necessitated that each mix of amatol be tested for density before loading. Cavitation was frequently the cause for the rejection of many loaded shell, although this trouble was almost entirely eliminated after much experimental work using Grade 2 T. N. T. for sealing. Even after this trouble had been overcome, every shell was tried with a pick, to see if this condition existed.

A great deal of the inspector's time was required for the reading, signing, and forwarding of property papers. It is thought that the presence of a property officer at each plant would have been of great advantage as it would have removed from the inspector's shoulders the burden of responsibility for property and would have enabled him to devote his entire time to inspection.

ACCEPTANCE TEST OF LOADED SHELL.

The acceptance tests of loaded shell were carried on in the same manner as the tests of the completed rounds and will be dealt with in a later paragraph.

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PROPELLANTS.

RAW MATERIALS.

With the exception of the acids, all raw materials were analyzed by the inspection forces at stated periods and the analyses made by the company were carefully scrutinized at all times. Very careful manufacturing inspection was carried on in all stages. Finished nitrocellulose was tested and approved before being colloided. Stabilizers were carefully analyzed. All treatments were inspected and regulated in accordance with standard requirements.

MANUFACTURING INSPECTION.

Inspection forces at powder plants were much larger than those of the explosive plants. A chief inspector was in charge, assisted by a chief clerk, a chief chemist and an assistant chief inspector, who were in turn assisted by technical, nontechnical, and clerical assistants. The total number at each plant varied from 4 at the Western Cartridge Co.'s plant, Springfield, Ill., to about 80 at the Old Hickory smokeless powder plant, Nashville, Tenn. Detailed instructions regarding the various procedures of inspection and inspection tests were contained in the "Inspection Manual" referred to above.

In general, the same procedure of careful inspection of manufacture obtained as in the explosives plants. The inspector was not empowered to accept smokeless powder; nor were the district offices, as will be explained later. In order to increase the general efficiency and to hasten shipments, inspection was carried on jointly with the French, British, and Belgium Governments on materials sold them by the United States Government. In general, the work was identical with that given above.

ACCEPTANCE TESTS OF SMOKELESS POWDER.

In addition to the line inspection of the manufacture of smokeless powder, there are the acceptance tests on the completed product. When the finished powder is offered by the manufacturer for acceptance it is subjected to three classes of tests, namely, the chemical test, the surveillance test, and the ballistic test.

The chemical tests were carried on by the inspectors at the manufacturing plants. The ballistic tests were carried on either at the Government proving grounds at Sandy Hook or Aberdeen, or on ranges operated by the manufacturer, but under the supervision of the Inspection Division. The surveillance tests were all made at Picatinny Arsenal.

The chemical tests consist of measurements of the powder grain, determination of moisture, and total volatility, stability, etc. These tests were made immediately after the sampling of the powder. If the powder failed to pass any of the chemical tests, the inspector telegraphed the proving ground to which the ballistic sample had been sent not to proceed with the ballistic test. The results of the chemical tests were telegraphed to the Washington office and followed by the usual form of chemical description sheet reporting the test.

The ballistic test of the seacoast cannon powder and powder for 5-inch and 6-inch wheel mount guns and all railway cannon were made at Sandy Hook, with the exception of tests of powder for the 16-inch seacoast gun and a few tests of 14-inch powder. These latter tests were made in the Canal Zone, using guns in the coast defense, as no guns were available at Sandy Hook.

The ballistic tests of smokeless powder for mobile field artillery, with the exception of 75-millimeter field gun, were made at the Aberdeen Proving Ground. The tests on 75-millimeter powder were conducted entirely on the ranges of the manufacturers at the following points: Carneys Point, N. J.; Kenvil, N. J.; Mount Union, Pa.; Emporium, Pa.; Drummondville, Canada; Nitro, W. Va.; Old Hickory, Nashville, Tenn.

As the requirements for this gun were larger and more urgent than the others, the use of these ranges afforded a great saving in time and a considerable relief to the Aberdeen Proving Ground. The greater part of the testing for the 75-millimeter field gun was done at the Carneys Point Field Gun Range, which was established as standard for this gun.

Toward the end of the war, 155-millimeter howitzers were obtained and ranges were set up at Nashville, Tenn., and at Kenvil, N. J., thus diverting a large amount of testing in this howitzer from the Aberdeen Proving Ground and saving considerable time in acceptance.

Attempts to obtain a 155-millimeter Filloux gun for Nashville were unsuccessful until too late to be of any service.

The ballistic tests on small-arms powder were also carried on at ranges of the manufacturers with the exception that Picatinny Arsenal powder was tested at Frankford Arsenal. This work in peace time is all done at Frankford Arsenal, but it would not have been physically possible to carry on these tests at Frankford Arsenal, whose two ranges were already overtaxed with tests of small-arms ammunition. The greater portion of small-arms powder testing was accomplished at the Du Pont Experimental Station at Wilmington, Del., whose four ranges were early established as standard.

One main reason for establishing proving grounds at the manufacturing plants was that under the existing laws it was impossible to ship smokeless powder by express in sufficient quantities to supply ballistic samples for the tests. After considerable delay a ruling was finally obtained allowing smokeless powder, up to 100 pounds per train, to be shipped by express from the Nitro and Old Hickory smokeless-powder plants, but this was not a sufficient allowance to care for requirements of even 75-millimeter powder, as there were not enough trains per day to care for the samples from a day's output. In order to overcome this difficulty at the Parlin plant of the Du Pont Co. a special nightly freight service was inaugurated between Parlin, N. J., and Aberdeen, Md., the train also being used for shipments of ammunition samples from various shell-loading plants in New Jersey.

The ballistic test of smokeless powder consists of two parts—the establishing of the proper charges and the series of seven (later reduced to five) rounds for uniformity of velocity and pressure.

Upon the completion of the ballistic tests the proving ground wired or telephoned the results to Washington. If the reports showed both chemical and ballistic tests satisfactory, the powder was accepted, manufacturer and inspector notified by wire, and the Production Division notified, thus enabling them to order the powder shipped to the loading company. The acceptance was not withheld for results of surveillance tests. These tests require storage at 65.5° C. and 80° C., and require a number of weeks to complete. The usual ballistic reports were later forwarded to Washington, the charges checked, the powder officially accepted, and the recommended charges forwarded to the loading company.

According to policy outlined by Lieut. Col. Miles, jr., at the outbreak of the war the figures leading to the established charge of propellants were checked by two officers in the Washington office to prevent any possibility of recommending charges which would fail to give the service velocity. The importance of such a rule can hardly be overestimated.

In general, the policy adopted for the inspection of smokeless powder was for the inspector to hold closely to the specifications, and all waiving of the same was in the hands of the Washington office. This was necessary, as it was not thought that the field inspectors or even district officers had had sufficient experience, nor were they in touch with the condition of the demand for material, which condition is usually the only cause for waiving specifications. This policy also avoided any chance of dispute between the manufacturer and the plant inspector as to which material should be accepted.

The ballistic specifications were adhered to absolutely, the only allowance being made when there was immediate demand for the powder. Such cases were rare, as the smokeless-powder manufacturers were almost always well ahead of the requirements. In case large variations from specifications where speed in acceptance and ting was required, the policy of acting first and later securing proval of the Engineering Division was adopted. Such practice ough hardly proper in peace times was of great value in getting ick action. The decisions made at such times were always conmed by the Engineering Division.

At the Government powder plant at Picatinny Arsenal the line spection was carried on in the usual way without referring to the spection Division. The results were forwarded in the usual manr to Washington, however, and the acceptance accomplished there. The inspection forces at the smokeless-powder plants were under e control of the district officers, and all correspondence was forarded through them. This resulted in considerable delay on quesons of importance. In general, questions of policy which could not settled by the inspectors at the plants could neither be handled in e district offices. However, in the distribution of instructions, the ordination of methods, and in personnel and accountability maters, the district offices saved the Washington office great embarrassent. The ballistic inspectors at the ranges operated by the manuacturers were controlled directly by the Washington office, as there as not available in the district office anyone with ballistic experience. n matters of accountability and personnel, however, the ballistic nspector reported to the Army inspectors of ordnance at the powder lants and thus to the district office.

As above stated, the actual acceptance of smokeless powder was nade at the Washington office. This was found essential, as there were not sufficient trained engineers at the various ranges to accept he powder. Moreover, the recommended charges had to be checked by two officers and compared between the plants and forwarded to the proper loading company. Several attempts were made to have the acceptance transferred to the district or to the inspector at the powder plant.

Smokeless powder differs from high explosives and most other materials in that each lot of powder has a different charge for loading. This fact makes it necessary to handle smokeless powder entirely by lot number instead of in bulk. The Production Division found it necessary to maintain in Washington complete control of the supply of smokeless powder, and this is one reason which made it necessary for the Inspection Division to maintain centralized control of acceptance and charge recommendations.

In order to decrease the interval between sampling and acceptance use was made of the following: Telegrams of chemical compliance; special train service for samples to Aberdeen; special automobile truck service for samples to Sandy Hook; telegrams of ballistic compliance or telephone conversation double checked; preliminary telegrams of acceptance based on the chemical and ballistic compliance wires; special daily messenger service between Aberdeen and Washington to deliver ballistic reports.

By using the above methods it became possible for the Washington office to accept the powder within from 4 to 20 days of the time the sample was taken. This interval compares favorably with the time required in England, which was 4 weeks. The use of telegrams and preliminary acceptances saved approximately one month's delay in shipping the powder. This was because of the time required for making up record sheets, transmission in the mails, checking, making up acceptance sheets, recording, accepting, distributing, getting out shipping orders, etc.

In addition to the powder tested for acceptance there was a considerable quantity of 75-millimeter and 155-millimeter howitzer powder tested for the French Government. As this powder was originally contracted for by the United States, it was necessary for the United States to inspect, accept, and pay for it and subsequently be reimbursed by the French.

The ballistic tests of this powder were made in the presence of the French inspectors and according to their methods. Upon receipt of information that it was satisfactory to the French, it was formally accepted.

The chief difficulties met with by the inspection forces were caused by lack of sufficient materials and of uniformly made components for tests. Under the first of these two difficulties should be mentioned the lack of 155-millimeter Filloux guns for carrying on tests and a similar lack of 14-inch and 16-inch seacoast guns and 9.2-inch howitzers. The methods which were used to overcome such difficulties make an interesting story. In general it was possible to carry on the tests somewhere and in all cases the powder was accepted and ready before loading operations were interfered with.

Among the component materials for the tests with which difficulty was experienced should be mentioned the inferior quality of the .30-caliber components first furnished by Frankford Arsenal for ballistic tests of small-arms powder. It was found impossible to obtain the uniformity of velocity required by the specifications, and in attempting to locate the reason it was found that by using components furnished by the United States Cartridge Co. for .30-caliber ammunition the uniformity desired could easily be obtained. Components made by Frankford Arsenal were later improved so that it became possible to use them in the ballistic tests of powder.

From the foreign inspectors, particularly the French, there was learned the use of standard powder. Standard powder was first used by the Inspection Division in the tests of smokeless powder for the 75-millimeter field gun at the Carneys Point range in the summer of

1917. Since that time its use has gradually been extended until now (Jan. 1, 1919), we are in the process of adopting comparison of standard powder of known ballistic value with the ballistic acceptance tests of all smokeless powder. This reference of all ballistic results to a previously determined standard is one of the greatest advances yet made in methods of ballistic test.

The following table shows the number of lots of smokeless powder inspected during the period from April 1, 1917, to January 1, 1919:

Tested at Government proving grounds:		
Aberdeen	645	
Sandy Hook	594	
Total		1,239
Tested by Inspection Division:		
Carneys Point, N. J	449	
Old Hickory, Nashville, Tenn	17	
Emporium, Pa	66	
Mount Union, Pa	37	
Kenvil, N. J	28	
Drummondville, Canada	22	
Nitro, W. Va	13	
Canal Zone	10	
Total	642	
Total small-arms powder tested	771	
Total small-arms and cannon powder tested by Inspection Division		1,413
Grand total, Jan. 1, 1919		2,652

Each lot of cannon powder represented approximately 125,000 pounds and lots of small-arms powder were either 60,000 pounds or 25,000 pounds. The total number of pounds of small-arms powder tested was approximately 38,374,935 pounds. The total amount of cannon powder tested was approximately 275,160,000 pounds.

The total cost of inspection of a lot of smokeless powder depends entirely upon the size of the ballistic sample, which varies from 5 pounds on a lot of small-arms powder to 6,500 pounds on a lot of smokeless powder for the 16-inch gun. The total cost of inspection, aside from the ballistic tests, costs approximately $53 per lot. This does not include the cost of the Washington office.

COMPLETE ROUNDS.

ASSEMBLY INSPECTION.

The inspection during the assembly of complete rounds was conducted by the same inspectors that conducted the loading inspection. One hundred per cent inspection of assembly was made and complete instructions for the inspection were given in the "Instructions to Inspectors of Shell Loading." In general, the same conditions prevailed throughout as in the loading inspection.

ACCEPTANCE TESTS OF COMPLETED ROUNDS.

Upon completion of the loading, samples of each lot of ammunition were sent to the Aberdeen Proving Grounds as follows: One-half of 1 per cent on first lots of all ammunition, in no case less than 15 rounds; in subsequent lots one-tenth of 1 per cent, but never less than ten rounds. Data cards were forwarded with each lot showing powder data, lot number of ammunition, fuze, etc. The ballastic acceptance tests of shell were for order of detonation on graze impact and fragmentation. The tests of shrapnel were for ball pattern and recovery. Either the Army inspector of ordnance or the chief Army inspector, or both, were usually present at all tests, but they were not permitted to release any ammunition without authority from Washington.

Reports of the tests were forwarded to the Washington office for check and acceptance of the material. In order to hasten the acceptance and release of ammunition, samples were sent to Aberdeen by special train, and tests conducted on the following day. Reports were then telephoned to the Washington office, and, if satisfactory, telegram was addressed to the inspector at the loading plant releasing the ammunition. It was found impracticable to release ammunition by telephone, due to the numerous mistakes in hearing and lack of evidence in the inspector's hands that the released ammunition was satisfactory.

The cooperation of the Aberdeen Proving Grounds, where most of the ammunition was tested, certainly reflects credit upon their acceptance section. Every effort was made on their part to move samples as rapidly as possible.

During the months of August, September, October, and up to November 11, the need for shell was so urgent that an order from the Inspection Division allowed all shell to be shipped to the front without awaiting results of the ballastic test.

The ballastic report sheets were triple checked in the Washington office in order to prevent the release of poor ammunition. Complete records were maintained listing for each lot the components entering into its manufacture, size of lots, etc., in order that any ordinary question arising on ammunition made during the war might be answered.

Tolerances were extended beyond those in the specifications by officers of the Engineering Division in order to move the ammunition as the inspection was considered too tight to permit manufacturers to meet the requirements. These tolerances were in order until the signing of the armistice, November 11, 1918, when they were discontinued. Retests were ordered in all cases where tolerances allowed by the Engineering Division were exceeded. Few final rejections were made, and then not until many retests and special tests had proven the ammunition to be at fault.

Tests for recovery showed numerous cases of setback in the projectile, but on account of the lack of facilities at Aberdeen Proving Grounds for determining the extent of setback it was decided not to hold up any shell on this account, as it would be impossible for the explosive to get away from the booster case, and results did not warrant holding them up for this reason.

After numerous tests it was determined that the results obtained from the ball and case test did not justify the expense, extra work, and trouble involved; therefore, this test was ordered discontinued. The ball-pattern test was also a test which did not give results of sufficient value to justify its continuation.

There were several difficulties encountered in inspection. It was discovered that variation in muzzle velocity was excessive, in many instances because the first round was low, and upon investigation it was noted that these were results of the first rounds fired from a gun in the morning when the barrel was cold. Orders were therefore issued to the proving grounds to fire two or three rounds in each gun immediately prior to firing the regular tests when the gun had stood and the barrel had become cold.

It was discovered after a series of tests that the setter plug on the graduate time-train ring came in contact with the screen in the combination velocity and time of flight test, interfering perceptably with the latter part of the test, namely, time of flight; therefore, this test was segregated, and an order was issued to submit a minimum of 15 rounds for acceptance tests of shrapnel instead of 10, in order to conduct these tests separately. Therefore, 5 rounds were fired for velocity, 5 rounds for time of flight, leaving 5 rounds to be divided between the remainder of tests.

It is believed that a test where point detonating fuzes could be fired for impact against a concrete abutment would be a valuable adjunct to the present program, also a water recovery into which shell could be fired into a sand butt, the abrupt stopping of which causes upsetting and unnatural results. This test would eliminate the vast amount of excavation resulting when shell fired into the sand butt for recovery deflect and become difficult to find.

Some difficulty was encountered because of the fact that the Supply Division in handling ammunition handled it only in quantities without references to lot numbers. It therefore became necessary in trying to locate a lot of ammunition which had given unsatisfactory results to write to all arsenals and storage depots to which any ammunition had been sent in order to find out if they had any of the particular lot in question. Several attempts were made to have adopted the use of lot numbers, but due to the very large amount of extra work involved the authority for the change has not been granted.

CHAPTER VII.

SHIPMENT, STORAGE, AND ISSUE OF EXPLOSIVES.

The storage and distribution of explosives materials after their development, production, and inspection were the final steps in the explosives program of the Ordnance Department. To ship the material when completed, to store it (caring for it during storage), and to issue it to the service required not only considerable study of all production, as well as shipping conditions, but also the knowledge of the quantities and kinds of material that would be needed, in order that requisitions be anticipated and the material be in storage at the proper location for satisfactory distribution.

Complete records were kept of all items shipped to and from storage, in storage, and issued to the service. Owing to the immediate importance of sending material overseas, the Ordnance Department kept in telephone communication with manufacturing plants and the depots as to what was actually on hand.

PROCEDURE.

SHIPMENTS.

When the material was completed, inspected, and accepted, if it was to be loaded directly into shell, bombs, grenades, etc., shipment was made from the manufacturer directly to the loading plant or arsenal which would do the loading, in which case a shipping order authorizing shipment was issued by the Production Division. If the material was not to be used directly or the loading plant had no immediate storage facilities, the material was shipped to an ordnance depot for temporary storage, in which case the storage space was supplied and the shipping order to the manufacturing plant was issued by the Supply Division.

The destination of the shipment was determined through reports on estimated production, reports on estimated capacities, and information received through inspectors, production men in the field, and from the manufacturing and loading plants, as to progress made and requirements for fresh supplies of material.

Shipping orders for shipment from the plant to storage depots on the Atlantic coast were written for such loaded ammunition as had been tested and accepted. In many cases where it was necessary to expedite shipments overseas a certain procedure was followed. As soon as a lot of shell was loaded it was sent immediately to the depot, instead of waiting until the ballistic test at the proving ground was completed. At the same time the samples for testing were sent to Aberdeen. Generally the result of the test was known by the time the lot reached the depot where it would be held if a retest was necessary. After a shipping order had been written, however, it was necessary to obtain a transportation order from the Inland Traffic Service which before issuing the order, determined that the material could be properly handled at the depot to which shipment was desired.

All shipments of explosives and ammunition were made in compliance with the Interstate Commerce Commission regulations for the "Transportation of explosives and other dangerous articles by freight and express," and with Ordnance Pamphlet No. 1724, "Handling and Storing of Explosives and Ammunition," covering transportation not only by train but also by boat and motor truck.

The amount of smokeless cannon powder shipped to loading plants to date of January 1, 1919, was 114,970,000 pounds; amount shipped to storage, 56,527,000 pounds; amount of small-arms powder shipped to loading plants, 22,243,642 pounds; amount of small-arms powder shipped to storage, 4,162,526 pounds; amount of high explosives shipped to loading plants, 122,900,094 pounds; amount of high explosives shipped to storage, 79,396,295 pounds.

STORAGE,

When explosive material had been completed, inspected, and accepted storage space was provided until it was required for service, or as in the case of material stored to production account until it was needed by the loading companies. An arrangement was made with manufacturers for the storage of components and raw materials which were not needed immediately or for which distribution had not been determined, which arrangement relieved the Ordnance Department of the necessity for maintaining storehouses for raw materials and component parts, and also eliminated a large amount of unproductive transportation. In cases where an excess of raw material existed the production officer charged with following up the production of the explosives in question decided upon a place of storage depending upon where the material was being manufactured, where it was to be used, and upon general transportation conditions. Storage, while sometimes made at the manufacturing plant, was usually made at the loading plant which was to use it, or at an ordnance storehouse.

Due to the fact that the production of high explosives was in progress and so far advanced before shell loading started, it was necessary to store, temporarily, high explosives in bulk at some of the ordnance depots instead of shipping the material directly to the loading plant. In this case request was made for storage by the Production Division for the exact amount of explosives to be stored to production account.

When lots of powder were inspected and accepted they were shipped to the loading plant and stored to production account pending the loading operation, shipped to a supply depot and stored as a reserve supply to production account, or were shipped to a supply depot for storage to the supply account for issue to the service in bulk or to be made into charges for issue.

Loaded ammunition was sent to storage at the ordnance supply depots until it was shipped overseas or issued to camps, posts, or fortifications, nearly all of these depots being located on the Atlantic coast close to ports of embarkation, which greatly facilitated overseas shipments.

Storage in all cases was made in accordance with Ordnance Pamphlet No. 1888, covering the "Care and Test of Smokeless Powder and Other Explosive Materials," and No. 1872, covering "Seacoast Artillery Ammunition." Surveillance, as described in these pamphlets, was maintained while the material was in storage, and tests were made periodically to see that the material had in no way deteriorated.

ISSUE.

The ideal procedure governing the issue of material to troops in training or overseas is to supply the material solely from depots, production being sufficiently in advance of requirements to avoid direct issue from the manufacturer. Owing to the immediate demand at the beginning of the war, this procedure could not at first be followed, but this was done more and more as plants got under way.

When an arsenal, depot, or other organization was in need of ammunition, a request or requisition on regular requisition forms, or by letter or telegram, was sent to that branch of the Ordnance Department handling such matters. The supply officer decided if the request was to be granted fully, partly, or totally disapproved, according to information available as to the future movement of troops or existing conditions. Records were kept of action taken on all such requisitions.

In approving material for a camp or depot the supply officer could order the material either from an arsenal or a manufacturer. If the materials were available at an arsenal or depot an "Order for supplies" was issued for supply from that point. If ordered directly from the plant, a "Shipping order" was issued. Information as to the amount of material in progress of manufacture and the amount available for storage or issue was received from inspectors of ordnance at the manufacturing plants by weekly progress reports, so that when requisitions from camps or overseas were received, the amounts known to be available from these sources could be applied and a shipping order for the amount desired be issued, if sufficient material was not in storage or if in the judgment of the supply officer such material should be obtained directly from the manufacturer.

When a loading plant was in need of high explosives or propellants these materials stored to production account were reissued at the request of the Production Division and shipping orders were issued for transfer to the loading plant.

DIFFICULTIES.

From the very first difficulties arose which tended to delay or interfere with the shipment of explosives material and its storage until it was needed. However, it was possible to overcome most of these difficulties by a careful study of the situation.

TRANSPORTATION.

In the first months of the war shortage of cars was a serious handicap in the transportation of explosives materials. The restrictions placed by the Interstate Commerce Commission on shipments of this kind also interfered with prompt delivery of material completed. Priority orders were issued, however, for the material most urgently needed, and liberal interpretation of the Interstate Commerce Commission regulations regarding the containers to be used, type of cars, etc., was made, to expedite shipments until the desired number of cars could be obtained and other requirements could be complied with.

Lack of ships at first was a serious menace to the plans of the Ordnance Department. However, more ships became available, and later it became possible to send over far greater cargoes owing to the conservation of ship space, due to the packing of material so that its displacement was reduced to an absolute minimum.

Lack of good anchorage facilities offered another difficulty in the overseas shipments. In cases where time or lack of depot storage space was a consideration direct shipments were made from the loading plant to the ship if the plant had a dock of its own. Often material had to be loaded on lighters and towed out to the ships. All ıipments through the port of New York were handled in this way. 'his included shipments from Raritan Arsenal, Sandy Hook Supply 'epot, and T. A. Gillespie Shell Loading Plant. There was not ıfficient water at any of these wharves for loading directly to the ıips, so it was necessary to load the ammunition on lighters for 'ansfer to ammunition ships at explosives anchorages in the outer ırbor. The most satisfactory method of transfer was by means of ›ck type lighters, 600-ton capacity, but these could not be used in ormy weather.

A project was under consideration for the dredging of channels ıd the building of piers at Sandy Hook near the "Horse Shoe," where ımmunition could be transferred directly from cars to ships. This ıs abandoned, however, at the signing of the armistice.

The actual loading of the ammunition aboard ships was quite a rious problem. Every bit of available space must be utilized, and 't the storage of the material must be such as to eliminate any ıance of accident or disaster. Special magazines had to be built powder charges were shipped. For gas shell special fittings were ›cessary to prevent leakage. Loose shell had to be stacked between ırtitions made of cases of boxed shell, each loose shell having a pe grouting. Each kind of material sent over had to be packed ıd stored in a special way.

STORAGE.

The greatest difficulty encountered in the storage of explosives and aded ammunition was the lack of storage space. During the first onths of the war there were available for storage only 38,000 uare feet. It was therefore necessary to provide additional storage ›ace, which was done by establishing storage depots on the Atlantic ›ast, with the result that on November 11, 1918, available storage ›ace totaled 6,300,000 square feet.

While speed was an essential factor, and, for this reason and for .e sake of economy in cases of temporary construction, some of the agazines were of frame construction covered with noncombustible ding such as corrugated asbestos, it is stated by officers familiar with ıe principal ammunition and explosives depots established by the nglish and French that those established by the Ordnance Departıent are superior to those established by other Governments, espeally in regard to type of construction, location of the buildings, nd other features relating to the safety of the materials stored. The epots, in so far as possible, were located so that they would not ıdanger thickly settled communities, and were designed on the principle of unit losses. In spite of all care and precaution it has to be ›cognized that accidents are liable to occur, and therefore the depot was designed as to location and spacing of buildings, quantities and kinds of material to be stored, and fire protection necessary, etc.; with this in view, so that if such an accident did occur, the limit of accident would be one building or one unit only.

There were three standard types of buildings adopted. The largest type building, 50 by 220 feet, built of hollow tile with gypsum roof and concrete floor, was intended for the storage of ammunition. A building, 32 by 96 feet, of frame construction, and covered with corrugated asbestos, was designed for the storage of 500,000 pounds of bulk smokeless powder and a building of the same size but of hollow tile was designed for the storage of fuzes and primers. The third building was 26 by 42 feet in size and of either tile or corrugated asbestos, depending upon whether the storage was considered permanent or temporary and was intended for the storage of high explosives. The spacing between the high-explosives buildings was 400 feet, the capacity for storage 250,000 pounds. The spacing between the smokeless-powder magazines was 300 feet, and the spacing between the ammunition magazines was 300 feet.

It was necessary, however, in order to take care of large quantities of explosives manufactured before loading operations were well under way, to provide a certain small area in each depot for temporary storage of high explosives in bulk. As the program of manufacture ran constantly ahead of the loading program it was necessary in the emergency to utilize from time to time all types of buildings for storage of this material, but with few exceptions the limit of quantity was kept at 250,000 pounds in spite of the considerable quantities of lost space in the ammunition warehouses.

Due to the urgent need of storage space for explosives it was not even possible to complete the construction of the supply depots before they were first used for storage of ammunition and explosives; as fast as the magazines were completed material was shipped to the depot and stored.

One of the greatest difficulties arose with the signing of the armistice when it became necessary to acquire additional storage space for the vast quantities of ammunition produced in the last months of the war and which would not be shipped across. Temporary depots were rented and additions to permanent depots rushed to completion. The Inland Traffic Service placed an embargo on all explosives and required that a transportation order be given by them for any shipments of this nature. These were issued only when definite information was received as to the ability of a depot or storehouse to handle the material. Their refusal to give transportation orders to places where congestion existed was of great assistance in the satisfactory distribution of surplus material.

The total amount of ammunition shipped overseas up to the signing of the armistice is given below.

	Total shipped overseas.
Caliber .30	1,333,000,000
Caliber .45	232,000,000
Caliber 8-millimeter	244,000,000
37-millimeter low explosive	1,686,000
75-millimeter high explosive	2,866,000
75-millimeter shrapnel	5,308,000
75-millimeter gas	303,000
75-millimeter anti-aircraft shrapnel	80,000
4.7-inch gun shell	72,000
4.7-inch gun shrapnel	195,000
5-inch shell	7,000
5-inch P. C	7,000
6-inch gun shell	11,800
6-inch Cl. cart	11,800
155-millimeter howitzer shell	231,000
155-millimeter Cl. cart. H	222,000
9.2-inch howitzer shell without A and B	14,000
9.2-inch Cl. cart	14,000
3-inch stokes shell, complete	158,000
Off. grenades	173,000
B. & F. As. for O. G	173,000
Def. grenades	517,000
B. & F. As. for D. G	197,000
Rifle VB G	655,000
Detonating Mark III for VB grenades	655,000
Bombs Mark I	1,600
Bombs Mark III	15,500
Fuze Mark II	14,000
Fuze Mark III	2,864,000
Fuze Mark V	250,000
Phos. H. G	225,000
Gas H. G	175,000
B. A. for Mark II	1,201,000

War Department,
Office of the Chief of Ordnance,
Washington, June 20, 1919.

Form 1942.
Ed. June 20–19—500.

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